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Nationwide Urban Runoff Program Comparison of Nonpoint Pollution Loadings from Suburban and Downtown Central Business Districts

Metropolitan Washington Council of Governments
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COMPARISON OF NONPOINT POLLUTION LOADINGS FROM SUBURBAN AND DOWNTOWN CENTRAL BUSINESS DISTRICTS

A Final Report

Prepared for

Metropolitan Washington Council of Governments

Under Task 4d of NVPDC-COG NURP Subcontract

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This project tested the hypothesus that nonpoint source loading factors in the downtown Washington , D.C., Central Business District (CBD) would be higher than those in a suburban CBD. Two Washington, D.C., CBD test watersheds were sampled, and their loading characteristics were compared with results of a study done previously in a suburb in Arlington County, VA. The report concludes by recommending nonpoint pollution loading factors for planning studies of suburban and downtown CBD's.

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COMPARISON OF NONPOINT POLLUTION LOADINGS FROM SUBURBAN AND DOWNTOWN CENTRAL BUSINESS DISTRICTS

Introduction

Nonpoint pollution loading factors (1) for 208 planning studies of central business districts (CBD) in the Metropolitan Washington region are based on a 1976-1977 field study (2) of loadings from a CBD area in Arlington County, Virginia known as "Parkington." Since Parkington is located in the Virginia suburbs, there is some concern that CBD loading factors based on this test watershed may not be representative of nonpoint pollution loading rates from CBD areas in downtown Washington, D.C. Specifically, there is some concern that the higher traffic levels and higher levels of commercial/office activity found in Washington, D.C. CBD's would result in higher nonpoint pollution loads per unit area than those associated with a suburban CBD like Parkington. The purpose of the study described herein is to test this latter hypothesis with data from a 1978-1980 monitoring study of two CBD test watersheds in Washington, D.C. and, if appropriate, to develop adjusted nonpoint pollution loading factors for downtown CBD's.

The first section of this report describes: (a) the important physical features of the Parkington test watershed and the two CBD test watersheds in Washington, D.C.; (b) the characteristics of the monitoring period at each site; and (c) the monitoring and analytical procedures employed for the Parkington and Washington, D.C. field studies. The second section compares the nonpoint pollution loading characteristics of the Parkington CBD and the Washington, D.C. CBD watersheds. The final section recommends nonpoint pollution loading factors for planning studies of suburban and downtown CBD's.

This report has been prepared pursuant to Task 4d of the NVPDC-COG subcontract for the Metropolitan Washington NURP Study (3).

Description of the Two CBD Test Watershed Studies

Physical Features

The Parkington test watershed traverses 25.6 acres of commercial-office land uses adjoining the intersection of Glebe Road and Wilson Boulevard in northern Arlington. Runoff and nonpoint pollution loading samples were monitored in the 42-inch diameter storm sewer located on the west side of Glebe Road immediately south of the Wilson Boulevard intersection.

The two Washington, D.C. test watersheds traverse the commercial-office development in the K Street, N.W. business district between 18th Street and 20th Street. Maps of the two adjoining watersheds are shown in Figures 1 and 2. Site #102 is an 8.5-acre watershed which was monitored at a 24-inch diameter storm sewer flowing

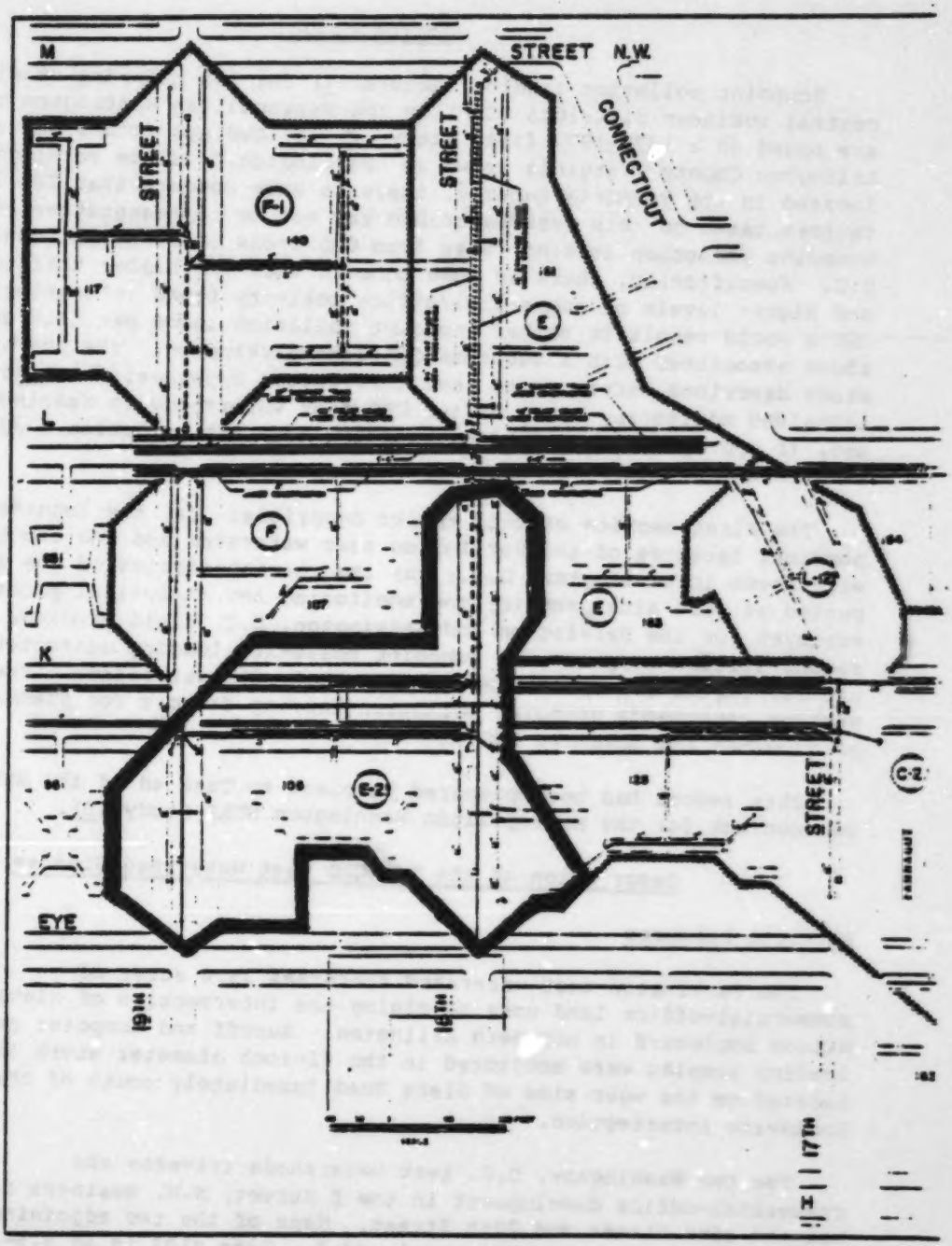

FIGURE 1. Generalized Map of D.C. CBD Site #102

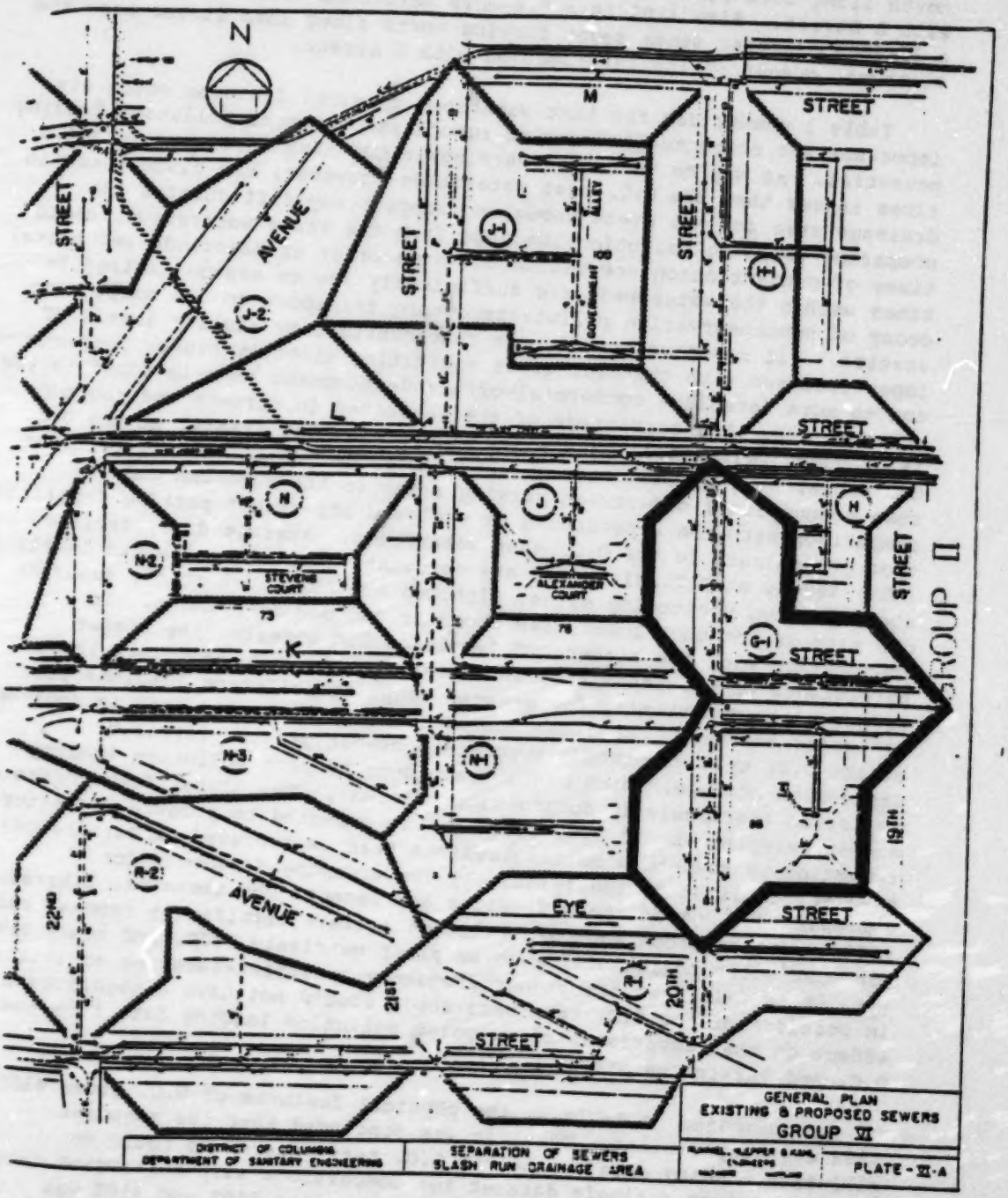

FIGURE 2. Generalized Map of D.C. CBD Site #103

north along 20th Street near the southeast corner of its intersection with L Street. Site #103 is a 5.6-acre watershed which was monitored at a 27-inch diameter storm sewer flowing north along 18th Street near the southwest corner of its intersection with L Street.

Table 1 summarizes the test watershed physical features which are important for characterizations of runoff and nonpoint pollution loading potential. As may be seen, the Parkington CBD test watershed is 3-4.5 times larger than the D.C. test watersheds; however, the differences in drainage area are not great enough to suggest any difficulties in comparing nonpoint pollution loadings from the three watersheds, since times of concentration are within the same order of magnitude and travel times within the watersheds are sufficiently low to assume negligible decay of nonconservative pollutants during transport to the monitoring station. All three watersheds are characterized by similar levels of imperviousness with the D.C. sites exhibiting slightly higher percentages due to more intensive commercial-office development than is found in the suburban CBD. The percentage of the watershed in streets and rooftops is, respectively, approximately 30%-35% and 40%-50% greater at the D.C. CBD sites, with the majority of the difference due to the existence of some ground-level off-street parking areas in the suburban CBD in comparison with the underground or enclosed off-street parking facilities that predominate in the D.C. test watersheds. Average daily traffic (ADT) levels at D.C. Site #102 are somewhat higher than traffic levels at the other two monitoring sites, although the ADT level at the suburban CBD site is not much lower than those at the downtown CBD's. In conjunction with the higher ADT levels on CBD streets, the higher percentages of watershed area in streets at the D.C. test watersheds suggests the opportunity for greater nonpoint pollution loadings from vehicular sources. The higher percentages of watershed area in rooftops at the D.C. test watersheds suggests somewhat greater levels of depression storage, which can achieve some nonpont pollution loading reduction (particularly during minor storms). The higher frequencies of street-sweeping at the D.C. sites can be expected to produce a greater reduction in suspended solids loadings than is achieved at Parkington; however, in light of the relatively low sweeping frequency for approximately 70% of the D.C. sites and because the technical literature indicates that broom sweepers will not achieve significant removal rates for most other pollutants, such as plant nutrients, BOD, and heavy metals (1), it is felt that the higher frequency of street-sweeping activities in portions of the D.C. test watersheds should not have a significant effect on the comparisons of nonpoint pollution loading data from the D.C. and Parkington sites.

As indicated in Table 1, the physical features of D.C. sites #102 and #103 are very similar. Thus, it was concluded that the nonpoint pollution loading data at the two D.C. test watersheds could be aggregated into a single dataset for comparisons with Parkington data. In addition, nonpoint pollution data from sites #102 and #103 was compared for 4 overlapping storms.

TABLE 1

COMPARISON OF CHARACTERISTICS
OF CENTRAL BUSINESS DISTRICT TEST WATERSHEDS

TEST WATERSHED CHARACTERISTICS	PARKINGTON	D.C. SITE #102	D.C. SITE #103
Total Drainage Area (Acres)	25.6	8.5	5.6
Percent Imperviousness (%)	95%	99%	99%
Streets: Percent of Watershed (%)	20%	27%	26%
Rooftops: Percent of Watershed (%)	33%	49%	47%
Curb Length (ft/acre)	310	345[a]	380[b]
Average Daily Traffic on Major Thoroughfare(s) (Vehicles/Day)[c]	Wilson Blvd.: 20,000 Glebe Rd. (North): 17,500 Glebe Rd. (South): 27,000	K St.: 34,500 18th St.: 15,400 19th St.: 13,700	K St.: 23,900 20th St.: 14,000
Street-Sweeping Activities	once/2 months (Broom sweepers)	30%: three times week 70%: once/2-3 wks (Broom sweepers)	30%: three times/wk 70%: once/2-3 wks (Broom sweepers)

[a] Does not include alleys which represent 10% of total street area

[b] Does not include alleys which represent 14% of total street area

[c] Based on 1976-1977 data for Parkington (VDH&T) and 1977 data for D.C. sites (COG)

Monitoring Period

The Parkington CBD test watershed was one of twenty-one small watersheds in the Occoquan River Basin and Four Mile Run Watershed monitored during an NVPDC-VPI&SU 208 study (2) between June 1, 1976 and May 31, 1977. A summary of monthly precipitation recorded at the National Airport NWS raingage during the monitoring period is presented in Table 2. Using the sequential discrete sampling procedure described below, total nonpoint pollution loads were determined for 14 storm events monitored during the field study. Precipitation volumes recorded for these 14 monitored storms, which produced a total of 73 runoff samples (i.e., an average of about 5 samples per storm), are summarized in Table 3. As may be seen in Table 3, the precipitation events covered by the Parkington CBD monitoring study include 2 storms in late fall, 2 storms in late winter and 10 storms in the spring months. Comparisons of observed rainfall volumes with the period of record means at the National Airport NWS raingage suggest that the late fall monitoring period was drier than normal while the late winter and spring monitoring periods were characterized by normal rainfall totals. The total rainfall volume produced by the 14 monitored storms was 5.6 in. (approximately 16% of the total annual rainfall volume during the 12-month NVPDC & VPI&SU monitoring study), with a mean storm event rainfall volume of 0.4 in.

The D.C. CBD test watersheds were monitored by O'Brien and Gere, Inc. from November 1978 through June 1980 to produce separated storm sewer loading data for the District of Columbia's Combined Sewer Overflow Study: Potomac-Anacostia River System. A summary of monthly precipitation at the National Airport NWS raingage during the monitoring period is included in Table 2 for comparison with rainfall volumes during the NVPDC-VPI&SU monitoring study. Although flow gaging problems prevented the determination of total nonpoint pollution loads for any of the storms covered by the 20-month D.C. CBD monitoring program, sequential measurements of instantaneous concentrations at 3-4 minute intervals were taken during the 16 storm events summarized in Table 4. Nine storms were monitored at site #102, and 11 storms were monitored at site #103. Four of the 16 storms produced synoptic monitoring data at the two CBD sites. Approximately 200-300 instantaneous concentrations were recorded at the two D.C. sites for the 16 monitored storm events, with about 60% of the observations at site #103 (i.e., approximately 11-16 observations per storm) and about 40% at site #102 (i.e., approximately 9-13 observations per storm). As may be seen in Table 4, the precipitation events covered by the D.C. CBD study include 3 storms in the late fall of 1978, 3 storms in the late spring of 1979, 4 storms in the summer of 1979, 3 storms in the early fall of 1979, and 3 storms in the late spring of 1980. Comparisons of observed rainfall volumes with period of record means at the National Airport NWS raingage suggest the following characterizations of meterologic conditions during the seasons covered by the D.C. monitoring study:

TABLE 2

MONTHLY RAINFALL VOLUMES AT NATIONAL AIRPORT
RAINGAGE DURING NONPOINT POLLUTION MONITORING PROGRAMS

MONTH	NVPDC - VPI&SU MONITORING PROGRAM		D.C. CBD MONITORING PROGRAM			PERIOD OF RECORD MEAN
	1976	1977	1978	1979	1980	
JANUARY		1.50 inches		6.64 inches	2.85 inches	2.81 inches
FEBRUARY		0.66		5.62	1.16	2.55
MARCH		2.17		2.45	5.04	3.32
APRIL		2.66		1.88	3.28	2.77
MAY		1.73		3.55	2.64	3.87
JUNE	1.21 inches			2.99	1.68	3.43
JULY	4.54			3.43		4.10
AUGUST	2.13			5.41		4.73
SEPTEMBER	7.23			6.64		3.39
OCTOBER	7.76			5.54		2.99
NOVEMBER	0.85		2.31 inches	2.33		2.92
DECEMBER	1.99		4.00	0.85		3.17

TABLE 3
STORM EVENTS MONITORED
TO DETERMINE TOTAL NONPOINT POLLUTION LOADINGS
DURING PARKINGTON CBD FIELD STUDY

DATE	RAINFALL VOLUME* (inches)
November 21, 1976	0.06
December 7, 1976	0.96
March 13, 1977	0.86
March 13, 1977	0.23
March 18, 1977	0.06
March 22, 1977	0.80
April 2, 1977	0.72
April 4, 1977	0.22
April 5, 1977	0.25
April 24, 1977	0.47
May 2, 1977	0.24
May 2, 1977	0.10
May 4, 1977	0.31
May 6, 1977	0.32
TOTAL:	5.60 in.
MEAN:	0.40 in. (S.D.= $\pm$ 0.34 in.)

*Based upon an onsite recording raingage record

TABLE 4
STORM EVENTS MONITORED
DURING D.C. CBD FIELD STUDY

DATE	ESTIMATED RAINFALL VOLUME* (inches)	CBD WATERSHED
November 15, 1978	0.11	#103
November 29, 1978	0.48	#102 & #103
December 9, 1978	0.17	#102
April 27, 1979	0.41	#102
May 13, 1979	0.08	#103
June 17, 1979	0.60	#103
June 23, 1979	0.54	#102
June 30, 1979	0.34	#103
July 1, 1979	0.68	#103
September 5, 1979	1.15	#103
September 21, 1979	0.16	#102 & #103
October 1, 1979	1.19	#103
October 2-3, 1979	0.72	#102 & #103
May 12, 1980	0.15	#102
May 20, 1980	0.43	#102
June 3, 1980	0.61	#102 & #103
TOTAL:	7.82 in	
MEAN:	0.49 in (S.D.= $\pm$ 0.34 in.)	

*Estimated volume of rainfall corresponding to sequential measurements of instantaneous concentrations; rainfall estimates based upon mean of daily totals at O'Brien and Gere's Commerce Department Building gage (#9) and Rock Creek Pumping Station gage (#19), which were distributed with National Airport gage's hourly rainfall record to determine rainfall volume corresponding to 1-1.5 hr. period during which water quality samples were collected.

SEASON	METEOROLOGIC CONDITIONS
Late Fall 1978	Normal Wetness
Late Spring 1979	Normal Wetness
Summer 1979	Wetter than Normal
Early Fall 1979	Wetter than Normal
Late Spring 1980	Drier than Normal

The total precipitation volume for the 20-month monitoring period was approximately 8% higher than the mean for the period of record at the National Airport raingage, indicating that overall meteorologic conditions for the entire monitoring period may be characterized as slightly wetter than normal. By comparison, overall meteorologic conditions during the Parkington CBD field study may be characterized as slightly drier than normal.

The total rainfall volume produced by the 16 monitored storms at the D.C. CBD sites was 7.82 in (approximately 11% of the total rainfall volume during the 20-month monitoring study), with a mean storm event rainfall volume of 0.49 in which is approximately 23% greater than the mean storm event rainfall volume for the Parkington CBD field study. To provide further comparisons of meteorologic conditions during the D.C. and Parkington CBD field studies, the relative frequency table shown in Table 5 was developed for precipitation observations during monitored storm events. As may be seen, the relative frequencies of storm events with rainfall volumes in the range 0.1-0.5 in were similar for the two monitoring programs, while storms with total volumes greater than 0.5 in occurred more frequently during the D.C. CBD field study.

In summary, the D.C. CBD field study was characterized by somewhat wetter meteorologic conditions and a greater frequency of significant storm events than was the Parkington CBD field study. However, since the Parkington and D.C. CBD watersheds are almost totally impervious and therefore antecedent soil moisture conditions do not affect monitored nonpoint pollution loadings, it is felt that the different meteorologic conditions encountered during the two monitoring studies should not distort comparisons of water quality data. If the test watershed contained significant amounts of pervious cover, the contributions of the pervious fraction would be expected to be greater during the wetter monitoring period due to higher overall soil moisture levels; in other words, the pervious fraction would be a more prominent source of nonpoint pollution loadings during a monitoring period characterized by greater than normal wetness. But in the case of a CBD area which is 95%-99% impervious, the prominence of land surface sources of nonpoint pollution loadings is probably not significantly affected by meteorologic conditions since impervious areas will convert almost all rainfall to runoff regardless of whether the monitoring period is relatively wet or relatively dry. Thus, it has been assumed that the differences in meteorologic conditions during the two CBD, monitoring studies should not bias comparisons of nonpoint pollution loading characteristics.

TABLE 5

RELATIVE FREQUENCY TABLE FOR PRECIPITATION VOLUMES
DURING STORM EVENTS MONITORED AT CBD SITES

STORM EVENT RAINFALL VOLUME (inches)	PERCENTAGE OF TOTAL NUMBER OF STORMS WITHIN INDICATED CLASS INTERVAL	
	PARKINGTON CBD STUDY[a]	D.C. CBD STUDY[b]
0.0 - 0.1	22%	6%
0.11 - 0.3	29%	25%
0.31 - 0.5	21%	25%
0.51 - 0.8	14%	31%
0.81 - 1.2	14%	13%
TOTALS	100%	100%

[a] Based on 14 monitored storm events

[b] Based on 16 monitored storm events

Monitoring and Analytical Procedures

Both studies relied upon automatic samplers and flowmeters to collect sequential runoff samples at numerous points along the runoff hydrograph. For the Parkington CBD field study, the flowmeter activated the sampler at preselected stage increments so that a sufficient number of samples could be collected to characterize pollutant concentrations at the peak as well as on the rising and falling limb of the runoff hydrograph. For the D.C. CBD field study, the flowmeter activated the sampler at the start of a runoff event, whereupon the sampler proceeded to withdraw runoff samples at uniform time increments (i.e., generally 3-4 minutes) until all the containers in the sampler base had been filled approximately 1.0 to 1.5 hrs after the automatic sampler has been activated. Thus, whereas the sampling technique used during the Parkington CBD study was capable of characterizing the entire runoff hydrograph regardless of storm duration, the sampling technique used during the D.C. CBD study was capable of providing a complete hydrograph characterization only for storms of relatively short duration. Unfortunately, many of the storms covered by the D.C. CBD study had durations well in excess of 1-1.5 hrs, and thus no runoff samples were collected for significant portions of these storm events; further, such heavy emphasis on the initial stages of the runoff hydrograph which, in the case of highly impervious land uses, is typically characterized by the relatively high concentrations typical of "first-flush" conditions (2), could presumably produce overestimates of storm event mean concentrations since it ignores the latter stages of the runoff hydrograph which are generally characterized by lower pollutant concentrations.

Both monitoring studies relied upon storm sewer controls for flow gaging and the Manning equation for uniform flow to convert stage to flow rate. For the Parkington CBD study, the Manning roughness coefficient, n, was determined through chemical gaging techniques (2). For the D.C. CBD study, the roughness coefficient was based upon literature values (4). Continuous flow measurements and corresponding concentrations were available for all 14 storms listed in Table 3 for the Parkington field study, so that total pollutant loads could be computed for each storm event. Unfortunately, difficulties with the flow gaging equipment severely hampered flow measuring efforts during the D.C. field study. Malfunctions of the pressure transducer flowmeters at both sites #102 and #103 distorted all flow data collected during 1978 and 1979 (i.e., 13 storm events). Since flow data and corresponding concentrations are required for total load determinations, these flowmeter malfunctions prevented calculation of storm event loads for approximately 80% of the storm events monitored during the D.C. field study (5). The flowmeter malfunctions were remedied in time for the January 1980 - June 1980 monitoring period which covered three storm events; however, a review of the available flow data indicates that the flowmeter's stage readings at site #102 apparently exceeded the stripchart's full-scale deflection (associated with a flow rate of 16.9 cfs) for extended periods during the

storms of May 19, 1980 and June 3, 1980, thereby preventing the development of runoff hydrographs which accurately portray peak flow periods. Since the observed flow record for the May 12, 1980 storm at site #102 was too intermittent to accurately characterize the runoff hydrograph, it was concluded that only one storm event--June 3, 1980 at site #103--had sufficient flow data to permit total pollutant load determinations. As indicated below, the lack of storm event loading data tended to limit the comparisons of Parkington and D.C. nonpoint pollution data.

A tipping bucket raingage with a sensitivity of 0.01 in was maintained in the Parkington CBD watershed for the duration of the monitoring program. A continuous five-minute rainfall record was developed for the calibration of the NPS Model (8) to the Parkington watershed (2,9).

For the D.C. CBD study, two weighing-type raingages, which are less sensitive than the tipping bucket variety, were maintained a few miles from sites #102 and #103.* Since reliable flow rate data was not available for 15 of the 16 monitored storm events and only the initial 1-1.5 hrs of each storm was monitored, total load data required for model calibration studies was not available. Therefore, applications of the raingage data was limited to determinations of total rainfall volumes during the 1-1.5 hr runoff sampling period for each monitored storm event. Since only daily rainfall totals had been tabulated for the O'Brien and Gere raingages (#9 and #19), available hourly records for the National Airport raingage were used to compute the rainfall volumes shown in Table 4 from the daily totals at the two O'Brien and Gere gages.

Sample retrieval and preservation techniques employed during the two CBD field studies were relatively similar. Both studies relied upon similar analytical procedures, with automated analyses techniques (7) used for plant nutrient determinations. Comparisons of organic loadings measured during the two studies are complicated by the fact that the Parkington study relied upon COD as the indicator of organic contamination while the D.C. field study relied upon BOD. Comparisons of phosphorus loadings are complicated by the fact that, with the exception of the October 1, 1979 storm event, the D.C. study limited its analyses to total inorganic P (i.e., ortho-P plus condensed phosphates) while the Parkington study analyzed runoff samples for ortho P, dissolved P, and total P. In order to compare the phosphorus data from the two studies, some assumptions must be made about the ortho-P component of total inorganic P (TIP) in CBD runoff. Since the principal sources (e.g., detergents) of condensed phosphates are not expected to contribute to phosphorus loadings in urban runoff to any significant extent, it was felt that the TIP observations reported by the D.C. CBD study should be

*Readings at the O'Brien and Gere gages located at the Commerce Department building (#9) and Rock Creek Pumping Station (#19) were averaged for the analyses described in this report.

equivalent to ortho-P concentrations. Comparisons of ortho-P and TIP concentrations for the only storm event (October 1, 1979 at site #103) with analyses for both species provide some indication of the reasonableness of this assumption. As may be seen in Table 6, which presents the time series of instantaneous concentrations for the October 1, 1979 storm, ortho-P and TIP concentrations at site #103 were equivalent for 15 of the 21 synoptic observations during the 1.5 hr sampling period. The mean "TIP:Ortho-P" ratio for the sampling period is 1.13. The most striking features of the "TIP:Ortho-P" time series in Table 6 are the stability of the relationship between the two species for the majority of the storm and what could be interpreted as rather spurious appearances of condensed phosphates at certain points in the storm (e.g., 5:42 am, 5:45 am, 6:34 am) followed by the return of the stable "TIP:Ortho P" relationships 3-4 minutes later. Assuming that site #103 is characterized by separated storm sewers and that no spills occurred during the storm event, it is difficult to explain the sudden departures from a ratio of 1.0 in the time series in Table 6. It is conceivable that some laboratory errors during the manual procedures included in the TIP analysis, specifically during acid hydrolysis of the sample at boiling water temperature (6), which requires considerable care to minimize the conversion of some organic P to ortho-P, could possibly account for the sudden increases in the "TIP: Ortho-P" ratio midway through the October 1, 1979 storm and perhaps for the rather high ratios at the start of the storm.* Both the Parkington and D.C. CBD studies relied upon autoanalyzers for phosphorus analyses; however, due to the unintentional conversion of organic P to ortho-P which can occur during the acid hydrolysis stage of the TIP analysis, the manual procedures for the ortho-P and total P tests used for the Parkington study are felt to typically introduce lower errors than the manual procedures for the TIP analysis. Further analysis of the TIP data collected during the other 15 storm events suggests that reported TIP levels are often inordinately high in comparison with other constituent concentrations measured at the two D.C. CBD sites and in comparison with ortho-P concentrations observed during the Parkington CBD study, which could also conceivably be related to some laboratory error encountered during the acid hydrolysis stage of the TIP analysis. Nevertheless, since the comparison of TIP and ortho-P for the October 1, 1979 storm tends to support the assumption that the principal sources of condensed phosphate forms should not make a significant contribution to phosphorus loadings in urban runoff, it was assumed that TIP measurements at the D.C. CBD's should be equivalent to ortho-P.

*Analyses of total P loading data from the Parkington CBD watershed to determine the distribution between inorganic and organic fractions revealed that organic P typically represented 90%-95% of the total P load. This distribution seems to imply that the conversion of a relatively small percentage of organic P to ortho-P during the acid hydrolosis portion of the TIP analysis could produce a significant increase in the TIP concentration. For example, assuming the analysis of a sample with 95% of the total P in organic compounds, the conversion of only 1.0% of the organic P to ortho-P during the TIP analysis would result in approximately a 20% overestimate of the TIP concentration.

TABLE 6
COMPARISON OF TOTAL INORGANIC P(TIP)
AND ORTHO P CONCENTRATIONS MEASURED
DURING STORM OF OCTOBER 1, 1979
AT CBD SITE #103

TIME OF SAMPLE	TIP (mg/l)	ORTHO P (mg/l)	TIP : ORTHO-P
5:15 am	4.5	2.7	1.67
5:19	*	*	*
5:23	5.13	3.17	1.62
5:27	4.87	3.33	1.46
5:30	3.17	3.17	1.0
5:34	9.67	9.67	1.0
5:38	1.52	1.52	1.0
5:42	1.59	1.36	1.17
5:45	2.60	1.75	1.49
5:49	1.84	1.84	1.0
5:53	0.5	0.5	1.0
5:57	1.44	1.44	1.0
6:00	2.7	2.7	1.0
6:04	1.84	1.84	1.0
6:08	2.94	2.94	1.0
6:12	1.21	1.21	1.0
6:15	*	*	*
6:19	*	*	*
6:23	2.71	2.71	1.0
6:27	4.28	4.28	1.0
6:30	2.46	2.46	1.0
6:34	4.45	3.25	1.37
6:38	5.40	5.40	1.0
6:42	6.01	6.01	1.0

The quality control program for the Parkington field study consisted of the liberal use of in-house standards and blind samples supplied by USEPA offices in Cincinnati, Ohio. A complete range of standards was included for the analysis series (40 sample tray) performed each day. In addition, lab personnel were supplied with monthly blind samples for analytical performance checks. When duplicate samples failed to replicate within a given range, the analytical series was repeated, as it was when blind sample analyses fell outside a 95 percent confidence interval. Two sets of sample unknowns were also analyzed during the course of the field study, and the results were forwarded to the EPA Region III Analytical Quality Control Coordinator.

The engineering consultant responsible for the D.C. CBD field study operated a quality control program which relied entirely on the use of in-house standards (11). In general, the quality control program for the D.C. site study was reasonably similar to the one employed for the Parkington study.

Analysis of Nonpoint Pollution Monitoring Data

Mean Concentrations

Linear Models. When applied to runoff volumes projected for a particular land use classification, mean concentrations enable the engineer or planner to formulate nonpoint pollution loading rate projections for the period of interest. To derive mean concentrations for each constituent, previous 208 planning investigations (2,10) of the Parkington CBD nonpoint pollution data relied upon the development of simple linear regression models that relate a storm event's total runoff volume to the corresponding unit area loading rate. Mean concentrations derived in this manner are felt to be more accurate indicators of long-term nonpoint pollution loading potential than the arithmetic mean of instantaneous concentrations, since the latter approach does not account for the flow and loading rate assigned to the individual instantaneous concentrations and therefore it assigns an equal weight to each observation. The use of a linear model which accounts for the total load and total runoff volume associated with an instantaneous concentration time series for each monitored storm event is felt to produce a mean concentration which is representative of the land surface's long-term response to variable storm events and antecedent conditions.

For each urban land use category covered by the NVPDC-VPI&SU field study, the unit area pollutant loading rate (in units of "lbs/acre") and the runoff volume (in units of "inches") produced by each runoff event were plotted on the same graph, with the loading rate as the ordinate and the volume as the abscissa. Simple linear regression techniques were applied to each scattergram to empirically determine a mean annual concentration of runoff from each land use. The resultant model can be stated dimensionally in terms of mass (M) and length (L) as ML^{-2} versus

L. If the line of best fit to the data passes through the origin (i.e., the vertical intercept equals zero), the slope takes on the dimension of ML^{-3}. The slope is therefore dimensionally equivalent to a measure of concentration. Expressed as the quotient of areal pollutant load in "pounds per acre" and runoff volume in "inches," the slope of the line takes on units of "pounds per acre-inch." When an appropriate conversion factor is applied (1.0 lb/ac-in = 4.413 mg/l) the slope can be expressed in the more familiar units of "mg/l."

The method of least squares was employed to obtain lines of best fit for the data. It should be noted, however, that a functional relationship exists between flow and the mass of pollutant washoff that is inherent in the determination of the dependent variable term. It follows that the use of the least squares method may not result in the best linear unbiased estimator in the Gauss-Markov theorem sense.* Although other biased or nonlinear estimations such as distribution-free or non-parametric statistics might yield smaller variances, the least squares approach was chosen because of its simplicity and ease of application.

Lines of best fit were derived for total nitrogen (TN), total phosphorus (TP), TSS, COD,** and heavy metals monitored during the field study. Seasonal models were not derived since many of the test watersheds included in the NVPDC/VPI&SU field study did not have a sufficient number of total load estimates during certain seasons. Consequently, simple linear models of loading rate vs. runoff volume were produced from a data base developed over the entire twelve-month monitoring period. Since the models undoubtedly reflect the range of seasonal and climatic conditions encountered by the prototype watersheds, the resultant estimates of mean concentration are probably best considered in a long-term average sense rather than on a short-term or single event basis.

An analysis of the regression results indicated that the intercepts of the fitted lines were not different from zero for most of the cases tested. Students "t" statistics were used to find symmetric confidence intervals for the intercept term. The intercept was found not to be significantly different from zero in the majority of cases at the 95% confidence limit and in all cases at the 90% limit. From this information, the null hypothesis (intercept = 0) could not be rejected and it was concluded that the intercept term could be ignored with less than a 10% chance of error. Since it was concluded that the regressed lines passed through the origin, the slopes could be regarded as mean concentrations of runoff from the land use categories.

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* That is to say, the least squares estimator may not have a minimum variance within the class of linear, unbiased estimators.

** Runoff samples from the Parkington CBD site were not analyzed for BOD.

Acceptable correlation coefficients were derived for all TN, TP, COD, extractable lead (EPB), and extractable zinc (EZN) models except the EPB relationship for the townhouse/garden apartment classification. In general, unacceptable fits were derived for TSS, extractable iron and four other heavy metals which were found to be present in urban runoff in relatively small quantities.

The results of the regression analysis are shown in Table 7. The Parkington CBD results are shown in the "Central Business District (CBD)" row:

- Total N: 2.14 mg/l as N
- Total P: 0.315 mg/l as P
- COD: 120 mg/l
- Extractable Lead: 0.755 mg/l
- Extractable Zinc: 0.320 mg/l

These mean concentrations have been applied to annual runoff volume projections to derive annual nonpoint pollution loading rates for CBD land uses (2). Unfortunately, the lack of flow and total load data prevents the development of comparable mean concentrations for the D.C. CBD watersheds.

Arithmetic Means of Instantaneous Concentrations. Since similar linear regression techniques could not be applied to the D.C. CBD dataset, arithmetic means of instantaneous concentrations were computed with the Parkington and D.C. monitoring data. The mean concentrations, standard deviations, and maximum concentrations for Parkington, D.C. Sites #102 and #103, and the combined D.C. CBD dataset are summarized in Table 8. As may be seen, the standard deviations for most constituents approach and, in some cases, exceed the mean value. The relatively high standard deviations highlight the substantial variability within the instantaneous concentration datasets and suggest that the arithmetic mean may not be an acceptable measure of central tendency. Thus, the mean concentrations summarized in Table 8 should be used with caution.

The most striking feature of the Parkington mean concentrations reported in Table 8 is that the arithmetic means for total P, total N, extractable lead, and extractable zinc are considerably higher than the mean concentrations reported in Table 7 for the regression analyses. This can be explained by the fact that the computation of an arithmetic mean assigns equal weight to all instantaneous concentrations whereas the weight assigned to concentrations in the regression analysis is dependent upon the corresponding instantaneous flow rate as well as the total load and runoff volume during the storm event; therefore, a relatively high concentration that is associated with a relatively low flow rate (i.e., relatively low mass loading rate) receives a greater weight in the computation of the arithmetic mean concentrations shown in Table 8 than in the regression analyses yielding the mean concentrations shown in Table 7. For this reason, it is felt that mean concentration based on

Table 7. Mean Concentrations of Urban Runoff Based on Regression Analyses: 1976-1977 NVPDC/VPI&SU Field Study

LAND USE	NO. OF EVENTS	POLLUTANT				
		COD	EPB	EZN	TP	TN
Large lot Single Family Residential (0.1-2 DU/Acre)	11	116.04 (.970)	0.117 (.671)	0.122 (.742)	0.340 (.800)	3.55 (.975)
Medium Density Single Family Residential (2-8 DU/Acre)	24	125.7 (.854)	0.0940 (.583)	0.0516 (.529)	0.303 (.866)	2.42 (.922)
Townhouse/Garden Apartments (8-22 DU/Acre)	50	74.1 (.066)	0.149 (.141)	0.680 (.794)	0.285 (.906)	1.48 (.883)
High-Rise Residential (> 22 DU/Acre)	11	100.9 (.995)	0.253 (.995)	0.153 (.975)	0.289 (.99)	1.28 (.990)
Suburban Shopping Center	26	113.6 (.930)	0.310 (.735)	0.357 (.905)	0.237 (.900)	3.38 (.980)
Central Business District (CBD)	14	120.0 (.883)	0.755 (.707)	0.320 (.775)	0.315 (.721)	2.14 (.714)

KEY

MEAN CONCENTRATION, IN MG/L

(CORRELATION COEFFICIENT)

SOURCE: Ref. 10

TABLE 8

MEANS OF INSTANTANEOUS CONCENTRATIONS AT CBD TEST WATERSHEDS

CONSTITUENT	PARKINGTON			D.C. SITE #102			D.C. SITE #103			COMBINED D.C. SITES #102 & #103		
	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.
TSS (mg/l)	189. (73)	177.	711.	87.5 (121)	148.	930.	69.2 (185)	145.	940.	76.4 (306)	146.	940
BOD_5 (mg/l)	---	---	---	26.5 (98)	27.1	194.	41.6 (164)	107.4	860	36.0 (262)	86.8	860
TOTAL P (mg/l as P)	0.53 (73)	0.46	2.16	---	---	---	---	---	---	---	---	---
TOTAL DISSOLVED P (mg/l as P)	0.18 (73)	0.17	1.21	---	---	---	---	---	---	---	---	---
ORTHO P (mg/l as P)	0.03 (73)	0.09	0.76	---	---	---	---	---	---	---	---	---
TIP (mg/l as P)	---	---	---	0.50 (98)	1.15	7.72	1.36 (142)	3.07	18.8	1.01 (240)	2.51	18.8
TOTAL N (mg/l as N)	3.76 (73)	2.70	14.2	2.05 (88)	1.43	9.71	2.29 (105)	1.94	10.3	2.17 (193)	1.72	10.3
TKN (mg/l as N)	3.01 (73)	2.72	14.2	1.65 (115)	3.51	26.6	1.36 (150)	1.58	9.7	1.49 (265)	2.59	26.6
NITRATE-N (mg/l as N)	0.75 (73)	0.59	3.39	0.89 (100)	0.51	2.73	0.80 (105)	0.46	2.12	0.84 (205)	0.49	2.73
EXTRACT. LEAD (mg/l)	1.58 (73)	1.93	13.5	0.45 (89)	0.53	2.47	0.26 (65)	0.57	3.5	0.37 (154)	0.56	3.47
EXTRACT ZINC (mg/l)	0.63 (73)	0.70	5.20	0.36 (98)	0.34	2.61	0.15 (105)	0.27	2.0	0.25 (203)	0.32	2.61
COD (mg/l)	211.4 (73)	141.	660	---	---	---	---	---	---	---	---	---

linear relationships between unit area loading rates and runoff volumes are more accurate indicators of long-term nonpoint pollution loading potential than arithmetic means of instantaneous concentrations. Nevertheless, it was felt that the arithmetic means in Table 8 could be used for order-of-magnitude comparisons of nonpoint pollution characteristics at Parkington and the D.C. CBD's.

Comparisons of arithmetic mean concentrations at Parkington and the D.C. CBD watersheds indicate that phosphorus and lead exhibit the greatest disparity between the two study areas, while the closet agreement was exhibited by TSS, nitrogen forms (particularly nitrate), and zinc. The lower TSS levels at the D.C. CBD sites can possibly be explained by the fact that sites #102 and #103 were subjected to more frequent street-sweeping than was Parkington. However, typical pollutant removal rates (1) for broom sweeping operations with a frequency of once every two weeks are far too low to explain the D.C. study area's significantly lower mean concentrations of lead and lower mean concentrations of nitrogen and zinc. It is conceivable that some of the difference between mean concentrations of lead from Parkington and the D.C. sites could be attributed to greater use of lead-free gasoline during the three years since the NVPDC-VPI&SU field study was completed; however, since the monitoring data collected in highly impervious watersheds during the ongoing National Urban Runoff Program (NURP) is expected to determine whether any reductions in vehicular-related lead loadings that has occurred since 1976-1977, such conclusions based on the data presented in Table 8 are considered to be purely speculative at this point. Further, an analysis of lead concentrations in D.C. CBD runoff at various stages of the O'Brien and Gere monitoring study does not reveal a significant decline over the course of the 20-month period.

During the original NVPDC-VPI&SU study (2), the Parkington nonpoint pollution dataset was screened to remove spurious observations. As a check on whether spurious observations might be biasing the computations of arithmetic mean concentrations for the D.C. CBD sites, arithmetic means were computed for individual storms monitored at each site and trends were noted. Tables 9 and 10 summarize the storm event means, standard deviations and maximum values for each storm monitored at sites #102 and #103, respectively. While the relatively high standard deviations for most storms highlight the significant variability in the instantaneous concentrations recorded at 3-4 minute intervals, it is reasonable to assume that means which are an order of magnitude greater than the range of mean concentrations for the majority of storms in the dataset are highly suggestive of either changes in the source of pollutant loadings or spurious data. The most notable examples of extreme departures from the monitoring period norm are the mean and maximum TIP concentrations for the June 3, 1980 storm at site #102 and for the October 1, 1979 and June 3, 1980 storms at site #103. At site #102, the June 3, 1980 mean TIP concentration of 1.51 mg/l is well outside the range of mean concentrations (0.09 - 0.28 mg/l) for the six other monitored storm events. At site #103, the October 1, 1979 mean TIP

TABLE 9
MEAN CONCENTRATIONS FOR STORM EVENTS AT SITE #102

STORM EVENT	TOTAL SUSPENDED SOLIDS (mg/l)			BOD5 (mg/l)			TIP (mg/l as P)			TOTAL N (mg/l as N)			TKN (mg/l as N)			LEAD (mg/l)		
	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.
11/29/78	18.2 (6)	8.6	32.0	46.5 (6)	39.3	114.0 (8)	0.26	0.10	0.45	1.56 (8)	0.38	2.1	0.65 (8)	0.34	1.2	0.07 (1)	---	0.07
12/9/78	75.9 (9)	17.8	100.0	33.1 (9)	17.3	68.0	0.19 (12)	0.10	0.50	1.28 (12)	0.33	2.05	0.67 (12)	0.25	1.2	0.45 (11)	0.09	0.63
4/27/79	57.5	21.9	106.0	13.4	22.9	70.0	---	---	---	---	---	---	---	---	---	0.07 (6)	0.02	0.10
6/23/79	80.4 (5)	65.0	160.0	24.5 (6)	18.6	57.0	0.28 (5)	0.18	0.45	0.77 (5)	0.50	1.53	0.72 (5)	0.52	1.50	0.25 (6)	0.06	0.35
9/21/79	30.9 (12)	24.6	90.0	15.3 (6)	4.8	20.0	0.17 (10)	0.06	0.27	1.43 (11)	0.69	2.83	0.91 (11)	0.76	2.4	0.03 (1)	---	0.03
10/2-3/79	16.6 (20)	14.1	64.0	---	---	---	---	---	---	---	---	---	4.0 (18)	8.2	26.6	---	---	---
5/12/80	159.1 (15)	200.0	620.0	26.2 (15)	30.4	90.0	0.09 (14)	0.05	0.19	2.76 (8)	0.45	3.3	1.82 (14)	0.47	3.0	0.74 (15)	0.75	2.3
5/20/80	127.8 (24)	167.4	660.0	32.6 (24)	10.5	55.0	0.12 (24)	0.07	0.43	1.20 (22)	0.25	1.60	0.42 (24)	0.24	1.4	0.87 (24)	0.50	2.47
6/3/80	120.4 (24)	215.1	930.0	20.9 (24)	38.0	194.0	1.51 (25)	2.0	7.72	3.85 (22)	1.59	9.71	2.42 (23)	1.86	9.50	0.06 (25)	0.09	0.36

TABLE 10
MEAN CONCENTRATIONS FOR STORM EVENTS AT SITE #103

STORM EVENTS	TOTAL SUSPENDED SOLIDS (mg/l)			BOD 5 (mg/l)			TIP (mg/l)			TOTAL N (mg/l as N)			TKN (mg/l as N)			LEAD (mg/l)		
	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.
11/15/78	77.8 (4)	53.6	158.	49.5 (4)	23.3	75.	0.54 (4)	0.06	0.62	7.05 (4)	0.78	7.78	5.1 (4)	0.54	5.7	0.44 (4)	0.15	0.66
11/29/78	8.8 (24)	5.4	19.	120.2 (25)	190.1	780.	0.11 (25)	0.07	0.31	1.69 (25)	0.72	3.24	0.94 (25)	0.64	2.5	0.09 (1)	---	0.09
5/13/79	23.5 (2)	0.7	24.	12.5 (2)	2.1	14.0	0.09 (2)	0.0	0.09	0.22 (2)	0.0	0.22	0.20 (2)	0.0	0.20	---	---	---
6/17/79	248.0 (1)	---	248.	90.0 (1)	---	90.0	0.03 (1)	---	0.03	1.05 (1)	---	1.05	0.90 (1)	---	0.90	0.13 (1)	---	0.13
6/30/79	66.7 (23)	164.2	790	55.7 (19)	195.	86.0	0.20 (16)	0.24	0.89	1.17 (23)	0.92	5.13	0.76 (24)	0.99	5.10	0.21 (7)	0.38	1.05
7/1/79	6.2 (13)	3.4	14.	34.7 (24)	12.9	66.0	0.18 (24)	0.30	1.20	---	---	---	0.43 (23)	0.39	1.70	---	---	---
9/5/79	82.5 (24)	128.6	629.	9.3 (21)	14.7	60.0	---	---	---	---	---	---	---	---	---	0.42 (24)	0.86	3.47
9/21/79	67.0 (24)	74.4	292.	28.4 (22)	23.5	97.0	0.07 (24)	0.04	0.14	1.81 (25)	1.86	10.3	1.12 (26)	1.80	9.7	0.07 (1)	---	0.07
10/1/79	70.3 (24)	124.3	588.	10.5 (22)	14.0	57.0	3.95 (22)	3.4	16.1	---	---	---	---	---	---	0.18 (1)	---	0.18
10/2-3/79	119.1 (23)	241.	940.	---	---	---	---	---	---	---	---	---	1.69 (21)	1.57	5.98	0.20 (1)	---	0.20
6/3/80	102.4 (23)	199.	840.	23.5 (24)	60.8	304.	3.81 (24)	5.33	18.8	3.98 (24)	1.60	8.55	2.75 (24)	1.64	8.0	0.11 (25)	0.26	1.17

concentration of 3.95 mg/l and June 3, 1980 mean TIP concentration of 3.81 mg/l are well outside the range of mean concentrations (0.03 - 0.54 mg/l) for the seven other monitored storm events. Since the October 1, 1979 and June 3, 1980 storms occurred during the latter half of the D.C. CBD monitoring study, it is not inconceivable that these rather high TIP levels could be indicative of a major change in the character of the nonpoint source, such as a wastewater interconnection, a spill in the watershed, or a change in the land use (e.g., construction activity). However, if there were a major change in the nonpoint pollution source, one would expect the concentrations of other pollutants to exhibit a similar departure from the norm. The time series of instantaneous concentrations measured for these two storms is tabulated in Appendix A to supplement the comparisons of pollutant concentrations available from Tables 9 and 10. Examination of Tables 9 and 10 and Appendix A does not reveal any major changes in BOD or nitrogen concentrations that would suggest the introduction of wastewater into the urban storm sewer system. In fact, the June 3, 1980 storm at site #103 exhibits a mean total N concentration that is almost equivalent to the mean TIP concentration and a maximum TIP concentration that is more than double the maximum total N concentration, both of which are highly unusual "N:P" relationships in comparison with the results of the NVPDC-VPI&SU field study (2) which found "total N:total P" ratios in runoff from highly impervious land uses to be on the order of 4:1 to 7:1. Likewise, a review of the TSS data in the Tables does not indicate any major changes in sediment loads due to any construction activities in the watersheds. Since the concentrations of other pollutants fall within the ranges associated with other storm events and the TIP concentrations for these two storms are significantly different from the levels observed for other storms and well outside the range of values observed during the NVPDC-VPI&SU field study, it was felt that the TIP observations for the storms of October 1, 1979 and June 3, 1980 could be treated as outliers and dropped from the computation of arithmetic mean concentrations. While there are some other pollutants that exhibit what appear to be spurious mean concentrations for certain storms, such as TKN at site #102 for the storm of October 2 and 3, 1979 and BOD at site #103 for the storm of November 29, 1978, it appears that most of these means are influenced by a few rather high observations which may or may not be representative of onsite conditions at the time the runoff sample was collected. Thus, it was decided that the only observations which merited deletion from the mean concentration computations were the 71 TIP measurements for the storms of October 1, 1979 and June 3, 1980.

The revised mean TIP concentrations for the D.C. CBD sites, following the removal of the aforementioned outliers, are tabulated in Table 11 for comparison with phosphorus levels monitored at Parkington. As may be seen, the revised mean concentration of TIP is approximately 85% lower than the original mean and much closer to the phosphorus concentrations observed during the Parkington study. While the mean TIP concentration of 0.15 mg/l for the D.C. sites is well in excess of the mean ortho-P concentration of 0.03 mg/l for Parkington, the fact that the D.C. sites'

TABLE 11
MEANS OF INSTANTANEOUS CONCENTRATIONS
OF PHOSPHORUS FORMS FOLLOWING REMOVAL
OF OUTLIERS FROM D.C. CBD DATASET

CBD DATASET	TOTAL P (mg/l as P)			TOTAL DISSOLVED P (mg/l as P)			ORTHO-P (mg/l as P)			TIP (mg/l as P)		
	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.	MEAN	S.D.	MAX.
PARKINGTON	0.53 (73)	0.46	2.16	0.18 (73)	0.17	1.21	0.03 (73)	0.09	0.76	----	----	----
D.C. SITE #102	----	----	----	----	----	----	----	----	----	0.16 (73)	0.10	0.50
D.C. SITE #103	----	----	----	----	----	----	----	----	----	0.15 (96)	0.20	1.2
COMBINED D.C. SITE	----	----	----	----	----	----	----	----	----	0.15 (169)	0.17	1.2

mean concentration is reasonably close to Parkington's mean total dissolved P (0.18 mg/l), which is the phosphorus fraction considered to be most immediately available for biological activity, and approximately 70% lower than the mean total P concentration (0.53 mg/l) for Parkington suggests that phosphorus loadings at Parkington and the D.C. sites may not be radically different. It is conceivable that the differences between the ortho-P mean concentration at Parkington and the TIP mean concentration at the D.C. sites are indicative of a higher inorganic fraction of total P (e.g., 20% vs 4%), rather than a major difference in total P loadings in the two studies; yet, in the absence of total P data for the D.C. sites, it is difficult to confirm or refute this hypothesis. However, the higher mean concentrations of total N attributed to Parkington runoff and typical "nitrogen:phosphorus" ratios (2) associated with runoff from highly impervious land uses tend to reduce likelihood that total P loadings from the D.C. CBD sites are greater than the total P loadings from Parkington. Another possible explanation for the difference between the mean ortho-P and TIP concentrations reported for the two CBD study areas is laboratory error during the TIP analysis. For example, assuming that the ortho-P fraction represents approximately 4% of total P and that the remaining 96% is the organic fraction, the conversion of only 10% of organic P to inorganic P during the acid hydrolysis phase of the TIP analysis could result in a TIP measurement which is more than 2.0 times greater than the actual concentration. In light of the anomalies highlighted in Table 6 and what appears to be a series of spurious TIP observations shown in Appendix A, the potential contribution of laboratory error can not be ruled out. Likewise, data logging and coding errors may be a factor in the excessively high TIP measurements shown in Appendix A and in higher mean TIP concentrations for the D.C. CBD sites, since the D.C. CBD dataset, unlike the Parkington dataset, was apparently not cross-checked for outliers after laboratory observations had been loaded into the consultant's computerized data management system (11). Given all of the above, particularly the caveat regarding interpretations of mean values associated with relatively high standard deviations, it is felt that the most appropriate interpretation of the phosphorus data in Table 11 is that it suggests that the inorganic fraction of total P loadings may be greater in the downtown D.C. CBD.

Further comparisons of all pollutant concentrations monitored in the suburban and downtown CBD study areas are presented in a later section on nonparametric statistical analyses.

Mathematical Model Calibration Study

Of the two CBD study areas, only the Parkington watershed had sufficient data on flow rate, total load, and rainfall to support a model calibration study that would produce "land use-nonpoint pollution" relationships. The model used to derive these relationships from the field study loading data, was EPA's NPS Model (8). Calibration of the

NPS model of the Parkington watershed involved executing the model with a continuous five-minute rainfall record covering the monitoring period and iteratively adjusting "dry weather pollutant accumulation rates" (lbs/acre/day), which represent the pollutant loading potential of an urban land use classification, until there was acceptable agreement between simulated and observed storm event loads. Since the objective of the NPS modeling study was the characterization of runoff mass loads released into receiving waters, model calibration focused on reproducing unit area loading rates and/or mean concentrations (i.e., total load per unit volume of runoff) for each storm event rather than peak instantaneous concentrations or a history of concentrations during the event.

NPS models were calibrated to all the urban watersheds included in the NVPDC-VPI&SU field study (1,2,9). The pervious and impervious area accumulation rates that produced the best fit between simulated and observed pollutant loadings are shown in the top line of each cell in Table 12. The Parkington model results are presented in the row labeled "Central Business District." Least square regression lines were fit to both unit area loading rate and mean concentration data, and the slope and correlation coefficient for the model yielding the best fit is displayed in the second and third lines of each cell in Table 12. Since the intercept of the regression line was rarely significantly different from zero at the 90% confidence limit, the divergence of the slope term from the 45-degree line of equal values provides an indication of the agreement between observed and simulated data.

Based upon the results of intermediate steps of the NPS model calibration study (2,9), it is reasonable to assume that pollutant accumulation rates are directly proportional to either long-term mean concentrations or loading rates associated with highly impervious land uses. This assumption is used to adjust initial estimates of model parameters in order to achieve better agreement between observed or simulated loads. In other words, although insufficient data is available to conduct a model calibration study for the D.C. CBD sites, estimates of dry weather pollutant accumulation rates could be derived for D.C. CBD's by multiplying the Parkington values shown in Table 12 by the ratio of long-term mean concentrations or loads measured in the two study areas. Unfortunately, the standard deviations associated with the means of instantaneous concentrations in Tables 8 and 11 suggest that the mean values may not be an appropriate measure of central tendency and therefore that ratios of mean concentrations for the D.C. sites and Parkington probably do not constitute statistically defensible adjustment factors. However, it should be noted that the hypothesis that is being tested in the study described herein is that the downtown D.C. CBD is characterized by higher nonpoint pollution loadings than those monitored during the NVPDC-VPI&SU field study at a suburban CBD. With the exception of the relatively high mean concentration of TIP attributed to the D.C. CBD study area, the data in Tables 8 and 11 does not appear to support this hypothesis. With respect to the differences in phosphorus

TABLE 12. DRY WEATHER POLLUTANT ACCUMULATION RATES (LBS/ACRE/DAY) FOR PERVIOUS AND IMPERVIOUS FRACTIONS OF URBAN LAND USES

LAND USE	NO. OF EVENTS	RUNOFF VOLUME	TOTAL SUSPENDED SOLIDS		TOTAL NITROGEN		TOTAL PHOSPHORUS		C O D		EXTRACTABLE ZINC		EXTRACTABLE LEAD	
			PERV	IMPERV	PERV	IMPERV	PERV	IMPERV	PERV	IMPERV	PERV	IMPERV	PERV	IMPERV
LARGE-LOT SINGLE FAMILY RESIDENTIAL	13	**[.80]** (.96)	**1.0** [.00] (.86)	5.5	**.02** [.81] (.73)	.08	**.0035** [1.22] (.71)	.01	**.80** [.91] (.73)	1.2	**.0008** [.81] (.66)	.004	**.0002** [.81]^{A} (.90)*	.005
MEDIUM DENSITY SINGLE FAMILY RESIDENTIAL	17	**[1.14]** (.91)	**1.0** [.02] (.73)	5.5	**.02** [1.02]^{A} (.94)*	.08	**.0035** [1.30] (.85)	.01	**.80** [.80] (.81)	1.2	**.0008** [---] (---)	.004	**.0009** [---] (---)	.005
TOWNHOUSE/ GARDEN APT.	41	**[.85]** (.93)	**2.0** [.87] (.81)	5.5	**.04** [.93] (.73)	.08	**.007** [.84]^{A} (.69)*	.01	**1.60** [.80] (.66)	1.2	**.0016** [.78] (.75)	.004	**.0028** [1.15;.78]^{A} (.89 for 13 obs.; .82 for 12 obs.)^{A}	.006
HIGH-RISE RESIDENTIAL	7	**[1.06]** (.98)	**1.0** [.80]* (.60)*	3.5	**.011** [.81] (.94)	.065	**.0017** [.89] (.60)	.008	**.53** [---] (---)	2.0	**.0006** [---] (---)	.004	**.001** [---] (---)	.008
SUBURBAN SHOPPING CENTER	21	**[.70]** (.78)	**1.0** [.93] (.86)	2.5	**.011** [.78]^{A} (.84)*	.05	**.0017** [.82] (.77)	.006	**.53** [.80] (.66)	2.0	**.0006** [.71] (.74)	.008	**.001** [1.14;1.32]^{A} (.88 for 8 obs.; .77 for 13 obs.)^{A}	.01
CENTRAL BUSINESS DISTRICT	9	**[.97]** (.84)	**1.0** [.80] (.86)	2.5	**.011** [1.01]^{A} (.84)*	.09	**.0017** [1.36] (.91)	.01	**.53** [.90] (.85)	2.4	**.0006** [1.01] (.69)	.01	**.001** [.92] (.74)	.02

NOTES:

1. POLLUTANT ACCUMULATION RATES (LBS/ACRE/DAY) FOR PERVIOUS AND IMPERVIOUS FRACTIONS ARE SHOWN IN **BOLD-FACED PRINT** ON FIRST LINE OF EACH CELL; SLOPE OF REGRESSION LINE FIT TO PLOTS OF SIMULATED (DEPENDENT VARIABLE) AND OBSERVED (INDEPENDENT VARIABLE) VALUES FOR PERVIOUS/IMPERVIOUS COMPOSITE IS SHOWN IN [ ]'S ON SECOND LINE OF EACH CELL; CORRELATION COEFFICIENT FOR REGRESSION LINE IS SHOWN IN ( )'S ON THIRD LINE OF EACH CELL.
2. PERVIOUS FRACTION ACCUMULATION RATE WAS COMPUTED BY MULTIPLYING TSS ACCUMULATION RATE FOR PERVIOUS FRACTION BY POLLUTANT "POTENCY FACTOR" DERIVED FROM NPS MODEL APPLICATIONS.
3. [ ]* AND ( )* INDICATES THAT COMPARISON OF SIMULATED AND OBSERVED "MEAN CONCENTRATIONS" PROVIDED BEST AGREEMENT; OTHER REGRESSIONS ARE BASED ON COMPARISONS OF SIMULATED AND OBSERVED "UNIT AREA LOADING RATES".
4. LAND USE REGRESSION MODELS THAT EXHIBIT CORRELATION COEFFICIENTS WHICH ARE LESS THAN 0.50 ARE INDICATED BY [---] AND (---) UNLESS ACCEPTABLE FITS WERE DEFINED FOR INDIVIDUAL WATERSHEDS WITHIN EACH LAND USE CATEGORY, IN WHICH CASE THE REGRESSION RESULTS ARE INDICATED BY [ ]^{A} AND ( )^{A}.

loadings from suburban and downtown CBD's, the absence of total P data makes it difficult to conclude any more than that D.C. CBD's may be characterized by a greater inorganic fraction of total P loadings. Insufficient data is available to conclude that total P loadings from downtown D.C. CBD's are higher than suburban CBD loadings, although the higher mean concentration of nitrogen in suburban CBD runoff and typical "nitrogen:phosphorus" ratios associated with runoff from highly impervious land uses suggest that such a relationship is somewhat unlikely.

Nonparametric Statistical Analysis

The relatively high standard deviations evident in Tables 8 through 11, which are highly suggestive of a non-normal distribution, indicate that since the mean instantaneous concentrations have been seriously affected by infrequent high values, they may not be acceptable measures of central tendency. To overcome this problem, nonparametric or distribution-free statistical techniques can be used for analysis of the monitoring datasets (12). These statistical techniques assume no shape for the population distribution and therefore are valid for both normal and skewed distributions.

To test the hypothesis that downtown CBD's produce higher nonpoint pollution loadings than suburban CBD's, "box and whisker" diagrams were constructed in order to graphically compare the monitoring datasets for the Parkington and D.C. field studies (13). The important features of a "box and whisker" diagram are highlighted in Figure 3. The box is composed of three horizontal lines which represent the 25th (i.e., lower quartile), 50th (i.e., median), and 75th percentile (i.e., upper quartile) of the dataset. The vertical whiskers illustrate the relationship of any extreme values to the remainder of the dataset. In the "box and whisker" diagram, the median is the measure of central tendency and the departure of the 25th and 75th percentile lines from the median provides an indication of skewness. Comparisons of medians provide an indication of significant differences in populations, while the lengths of the boxes associated with each population may be compared to provide an indication of differences in variance, and the degree of symmetry about the median may be compared to provide an indication of differences in distribution.

For comparisons of nonpoint pollution loadings from downtown and suburban CBD's, "box and whisker" diagrams were developed from the following datasets:

1) Parkington CBD (all storms)
2) Combined D.C. Sites (all storms)
3) D.C. Site #102 (all storms)
4) D.C. Site #103 (all storms)
5) D.C. Site #102 (overlapping storms)
6) D.C. Site #103 (overlapping storms)

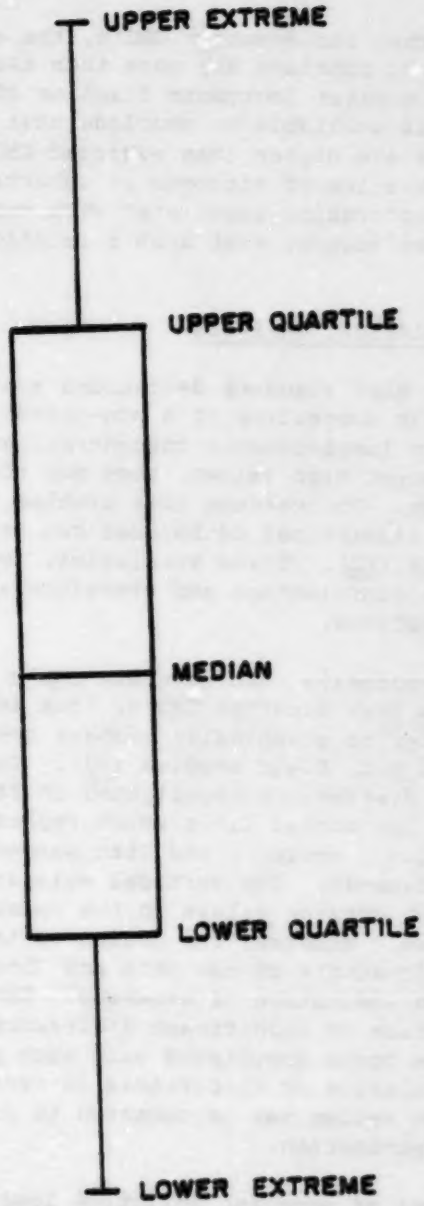


Figure 3. Configuration of a Box Plot

Comparisons of datasets 5 and 6 were intended to provide some indication of any differences in the nonpoint pollution loading potential of Sites #102 and #103, since relatively few observations in datasets 3 and 4 were made during overlapping storm events.

"Box and whisker" diagrams for instantaneous concentrations of total suspended solids (TSS), BOD_5, total N, TKN, nitrate-N, ammonia-N, lead, zinc, and phosphorus forms are shown in Figures 4 through 12. The mean instantaneous concentration is shown in each plot by a "+" to provide an indication of its relationship to the median value. Since the Parkington dataset does not include BOD_5 observations, typical COD/BOD ratios for commercial land uses covered by the NVPDC/VPI&SU field study (2) were used to derive a BOD_5 dataset from the COD observations in the Parkington dataset. The results are plotted in Figure 5(a). For comparison with the computed BOD_5 dataset for Parkington, a "box and whisker" diagram based on instantaneous concentrations (66 observations) monitored at Manassas Mall--one of the shopping center sites included in the NVPDC/VPI&SU field study--is plotted in Figure 5(b). Also, it should be noted that total P, total dissolved P, and ortho-P datasets for Parkington are included in Figure 12 for comparison with the TIP datasets for the D.C. sites.

In the case of TSS, BOD_5, lead, zinc, and TIP, the "box and whisker" plots for all six datasets clearly demonstrate the high variability and skewed distributions suggested by the relatively high standard deviations in Tables 8 through 11. The significant differences between the mean and median values in most datasets provide a further indication of a non-normal distribution. Initial analyses of the "box and whisker" plots focused on the differences among the combined and individual D.C. CBD datasets. In the case of overlapping storms at Sites #102 and #103 (datasets 5 and 6), "box and whisker" plots for almost all constituents are surprisingly similar in terms of median values, variance, and skewness, suggesting that the nonpoint pollution loading potential of the two D.C. CBD sites are similar and that the individual datasets (i.e., 3 and 4) composed of synoptic and nonsynoptic storms can be combined without introducing significant bias. In the case of the individual D.C. site datasets composed of all observations, there are somewhat greater differences between Sites #102 and #103 for most constituents, but the box lengths, skewness, and median values associated with each site are similar enough to suggest that the populations are not significantly different. In light of the similarities in the "box and whisker" diagrams for overlapping storms, differences in the individual Site #102 and Site #103 datasets covering all storms can probably be attributed to differences in meteorologic conditions associated with monitored storm events (e.g., precipitation, duration of dry weather period between storms, antecedent precipitation). In summary, since the analysis of "box and whisker" diagrams for the individual D.C. sites suggests that any differences between the two populations can be attributed to exposure to different meteorologic conditions rather than to differences in nonpoint pollution loading potential, it would seem

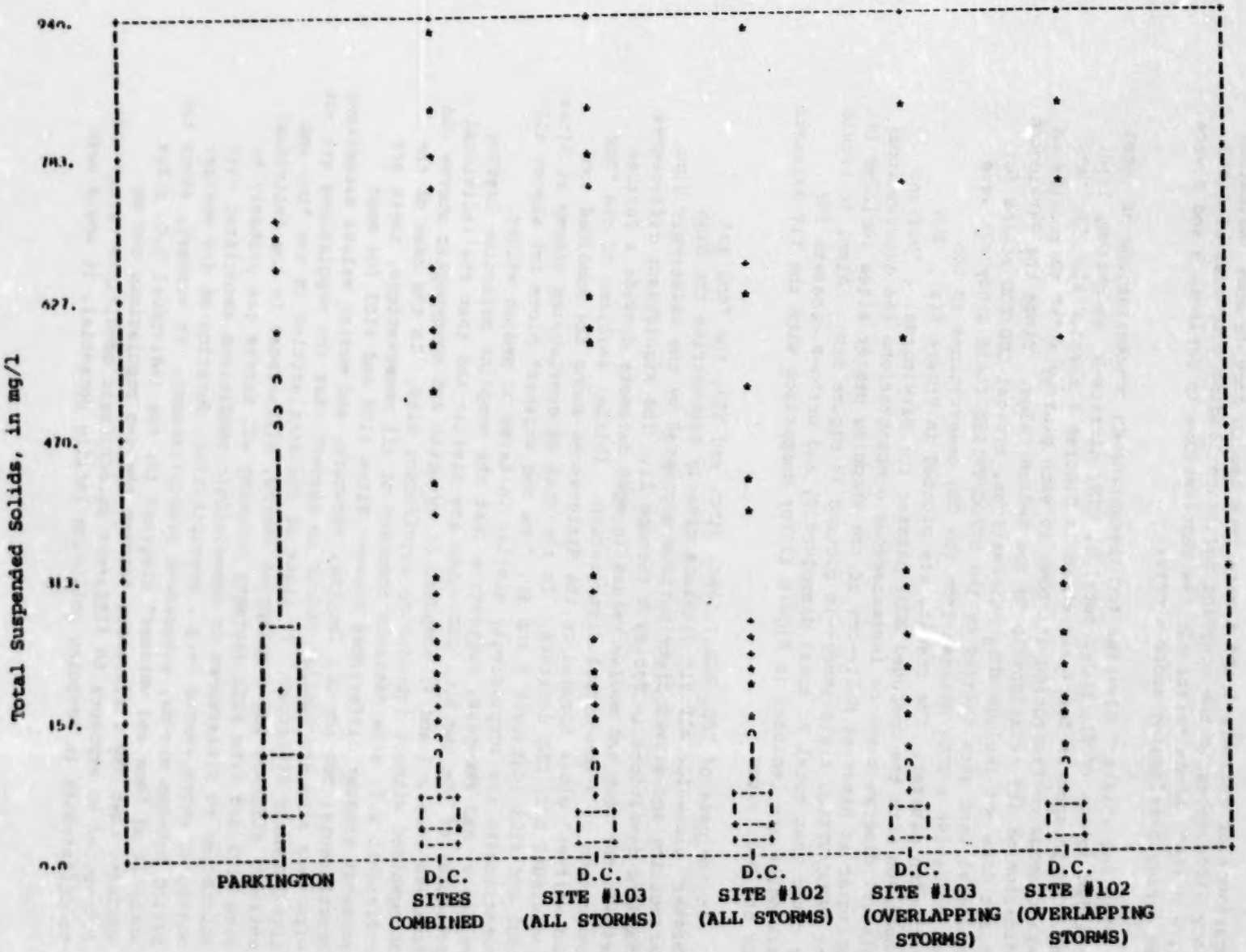


Figure 4. "Box and Whisker" Diagrams for Total Suspended Solids

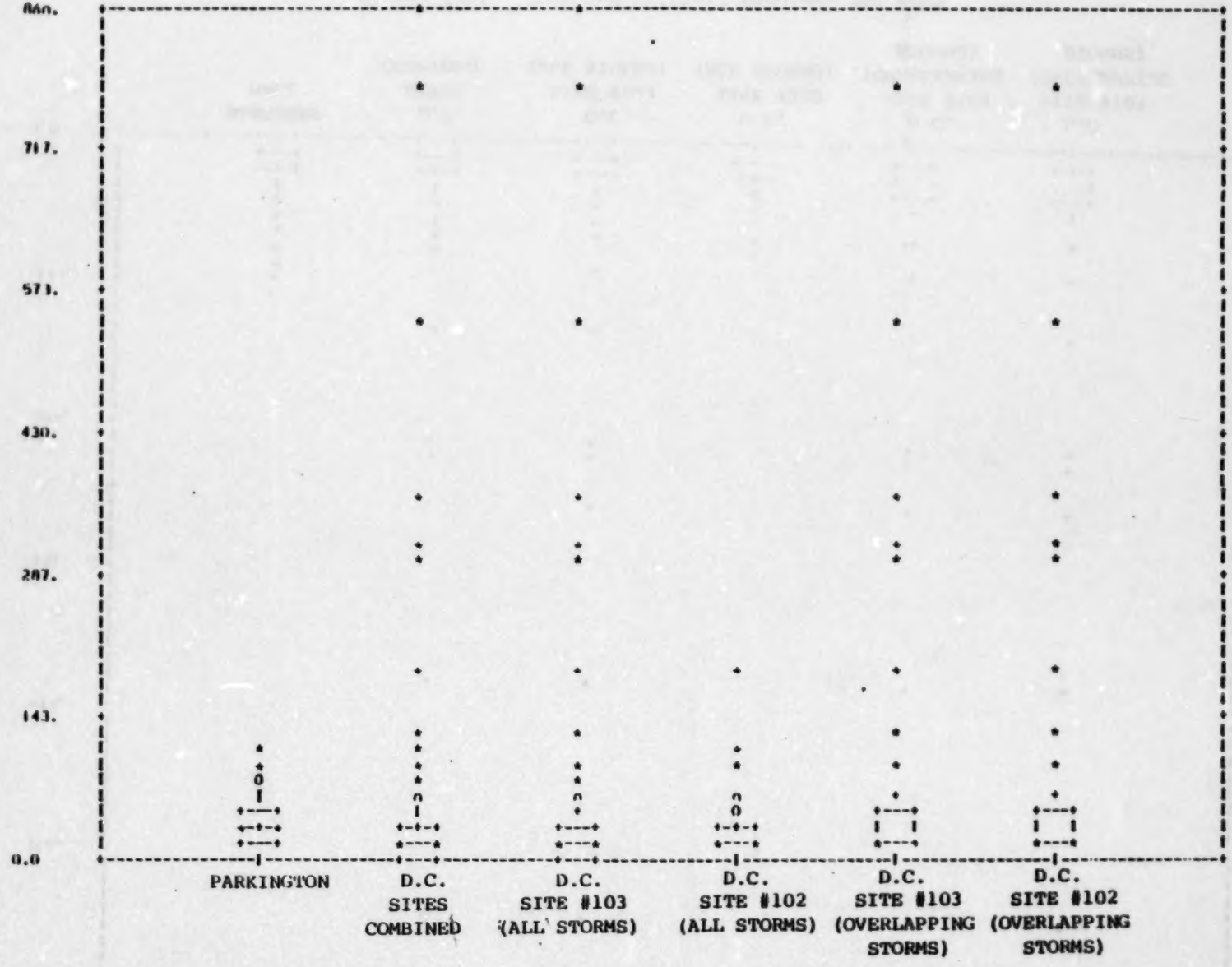


Figure 5(a). "Box and Whisker" Diagrams for BOD5

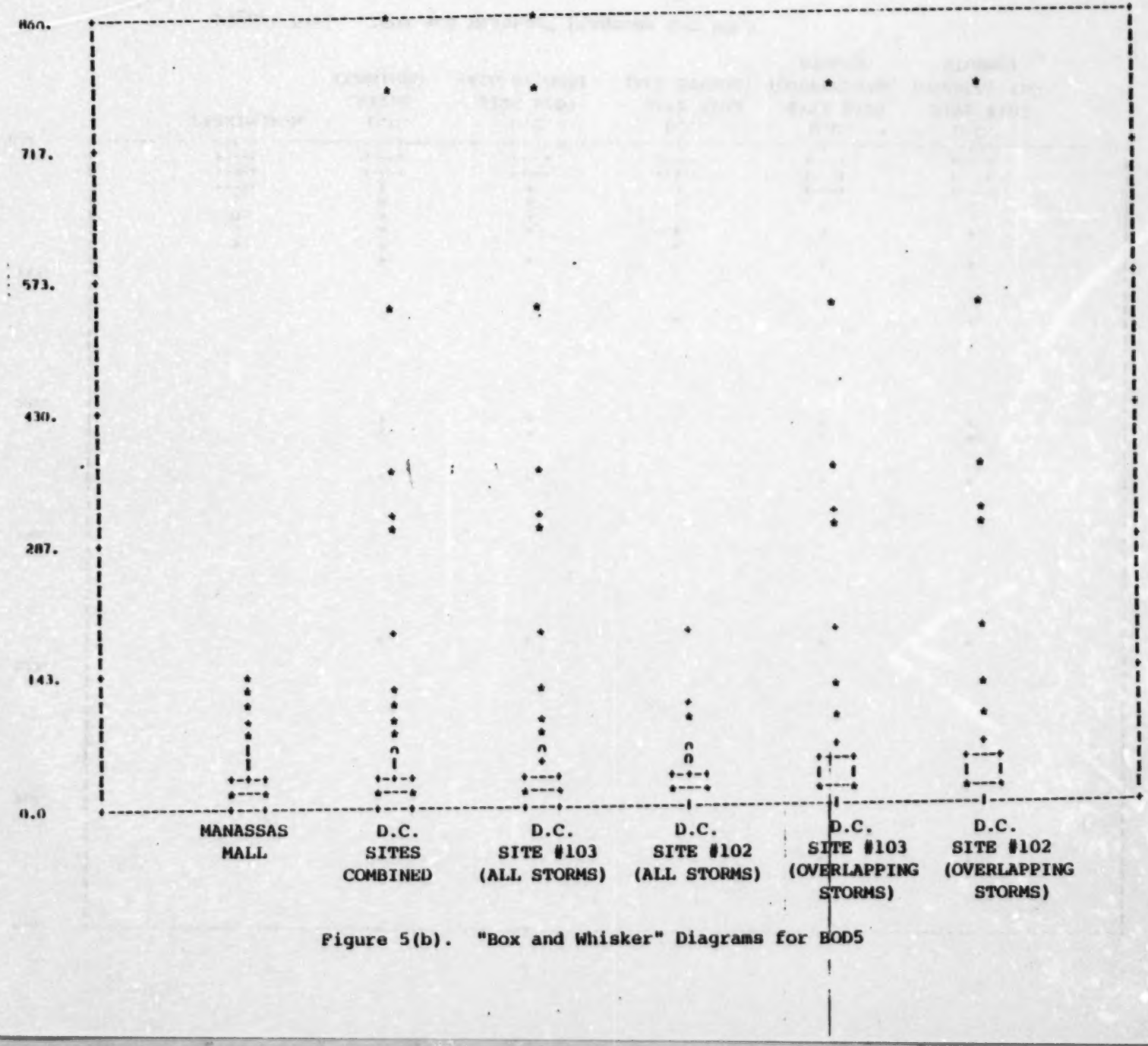


Figure 5(b). "Box and Whisker" Diagrams for BOD5

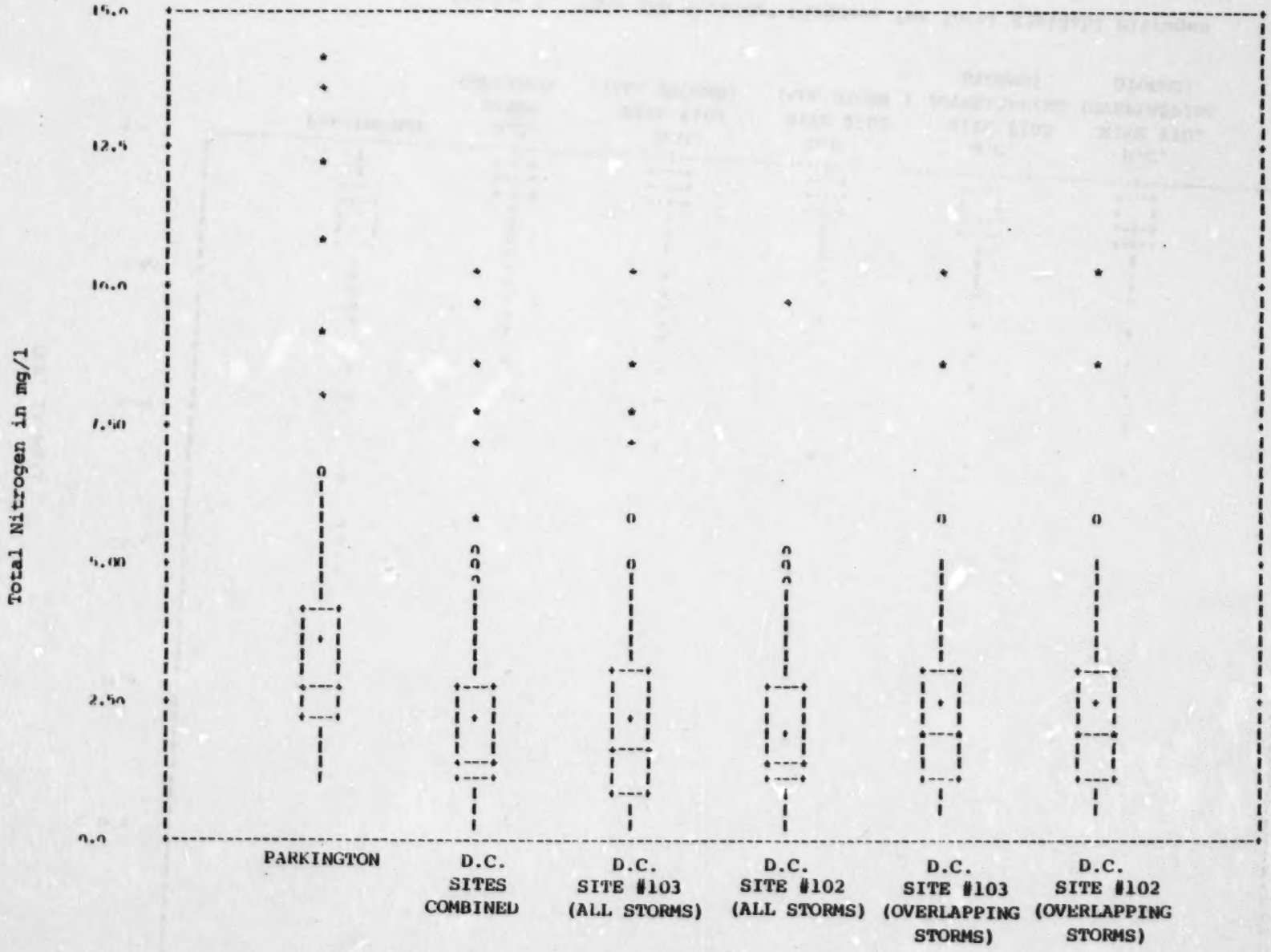

Total Nitrogen in mg/l
PARKINGTON
D.C. SITES COMBINED
D.C. SITE #103 (ALL STORMS)
D.C. SITE #102 (ALL STORMS)
D.C. SITE #103 (OVERLAPPING STORMS)
D.C. SITE #102 (OVERLAPPING STORMS)

Figure 6. "Box and Whisker" Diagrams for Total Nitrogen

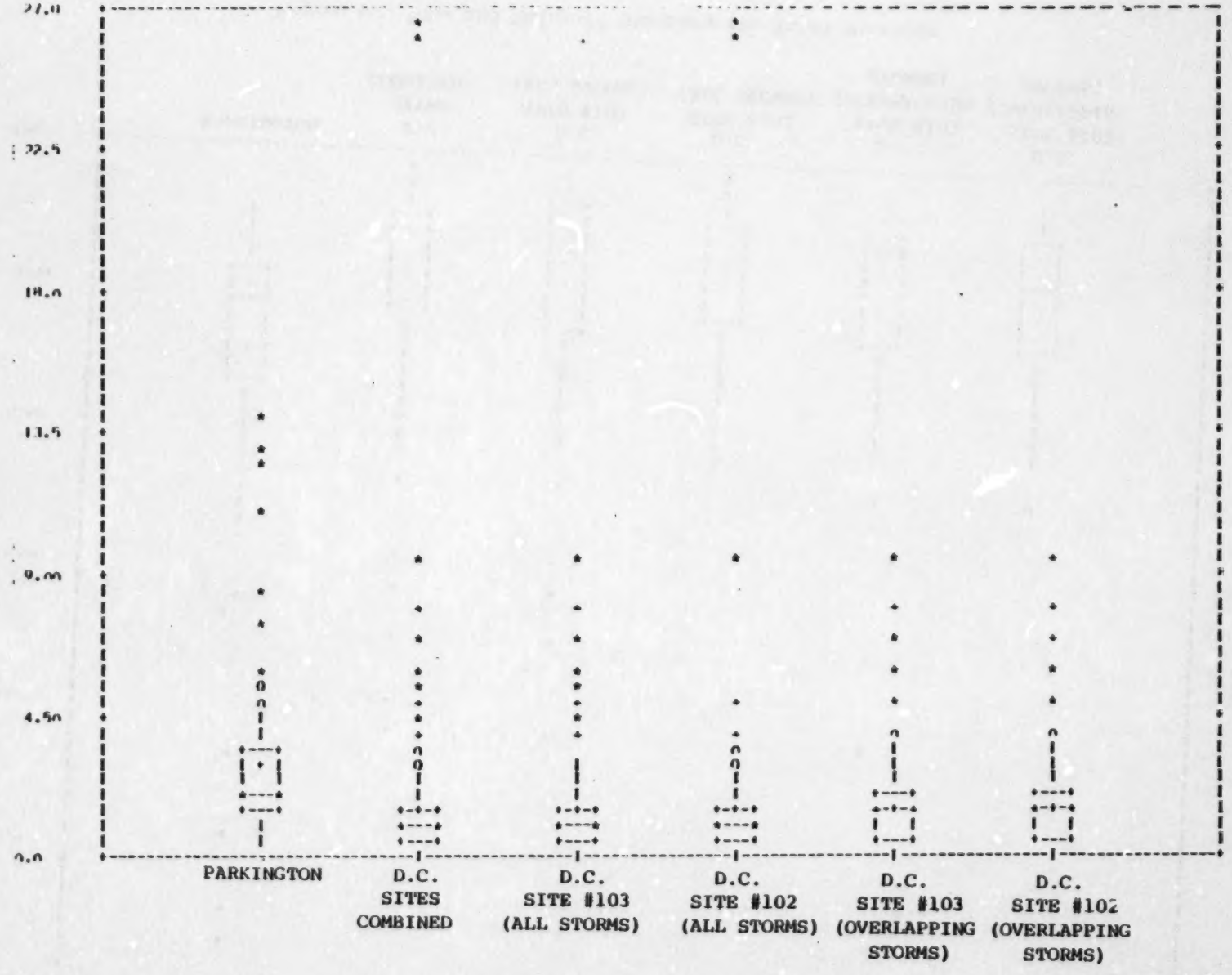


Figure 7. "Box and Whisker" Diagrams for Total Kjeldahl Nitrogen

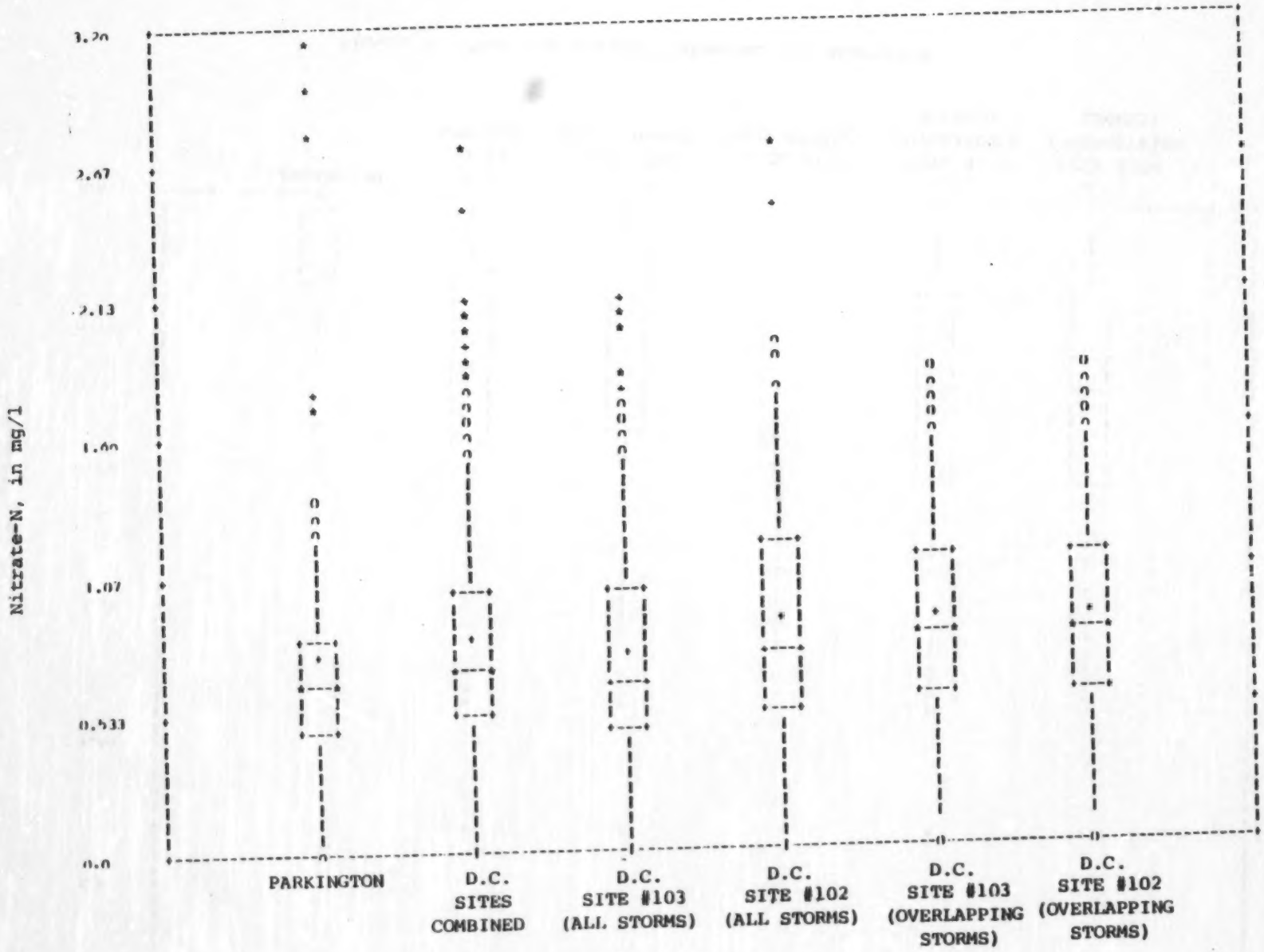


Figure 8. "Box and Whisker" Diagrams for Nitrate-N

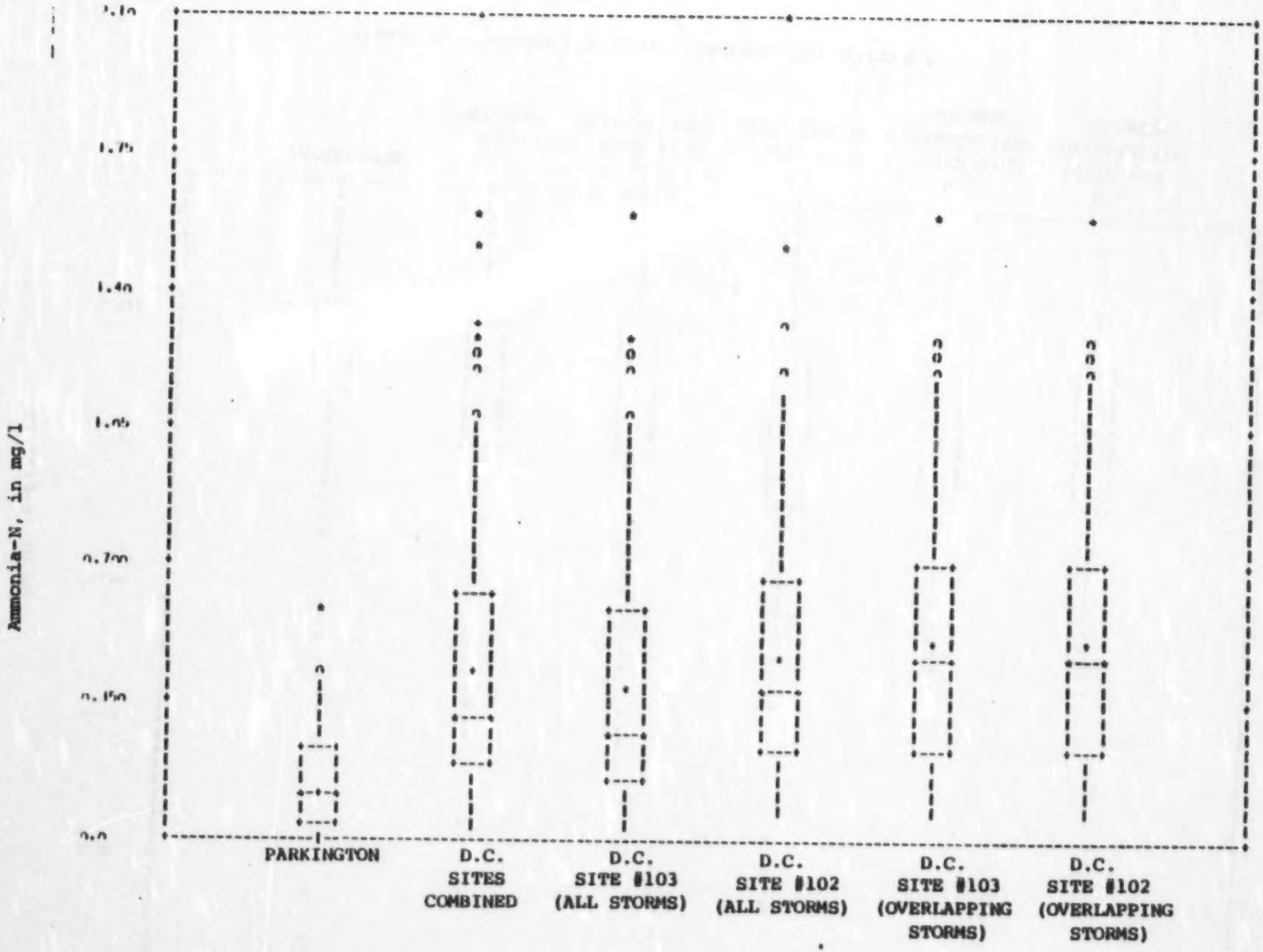


Figure 9. "Box and Whisker" Diagrams for Ammonia-N

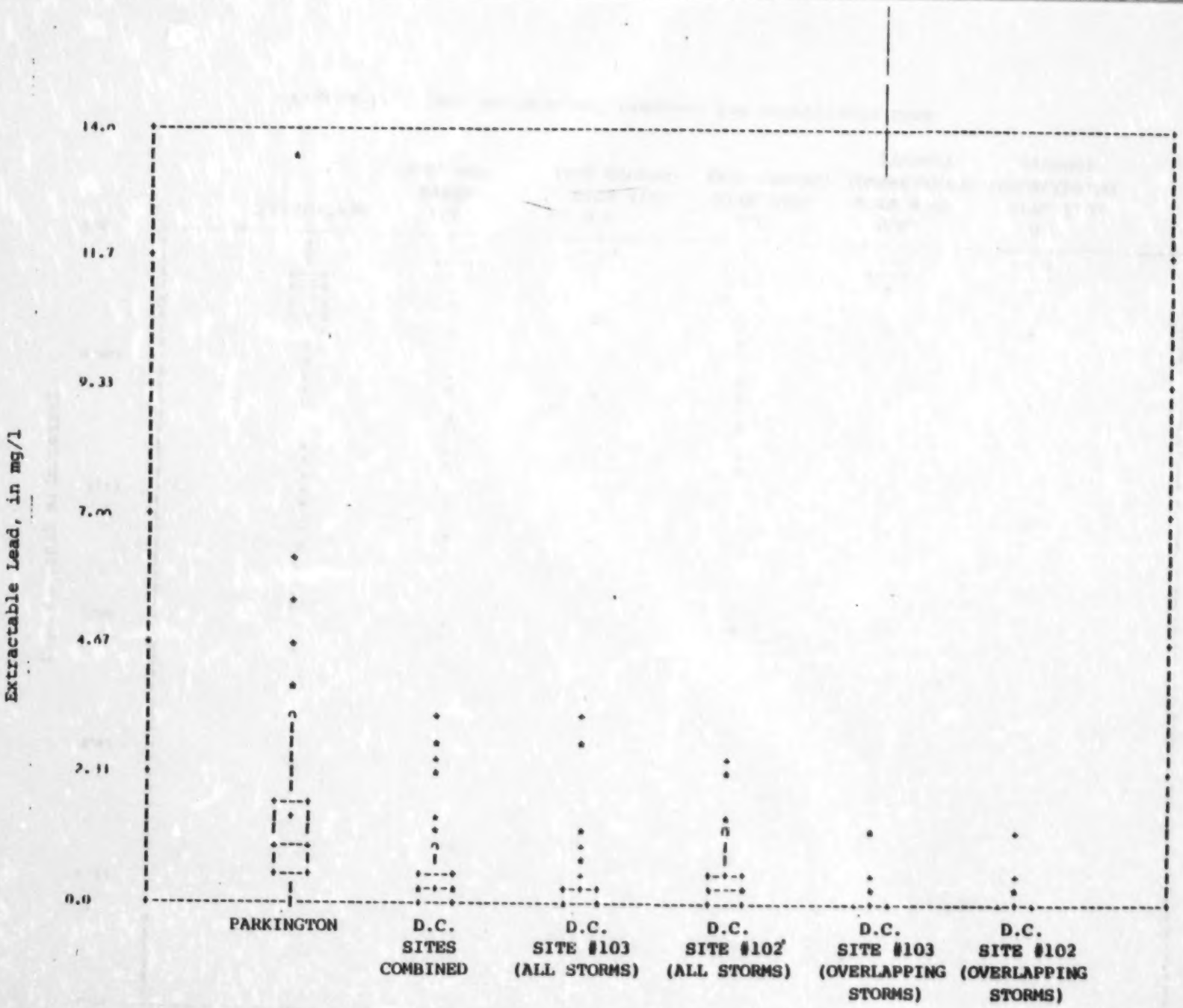


Figure 10. "Box and Whisker" Diagrams for Extractable Lead

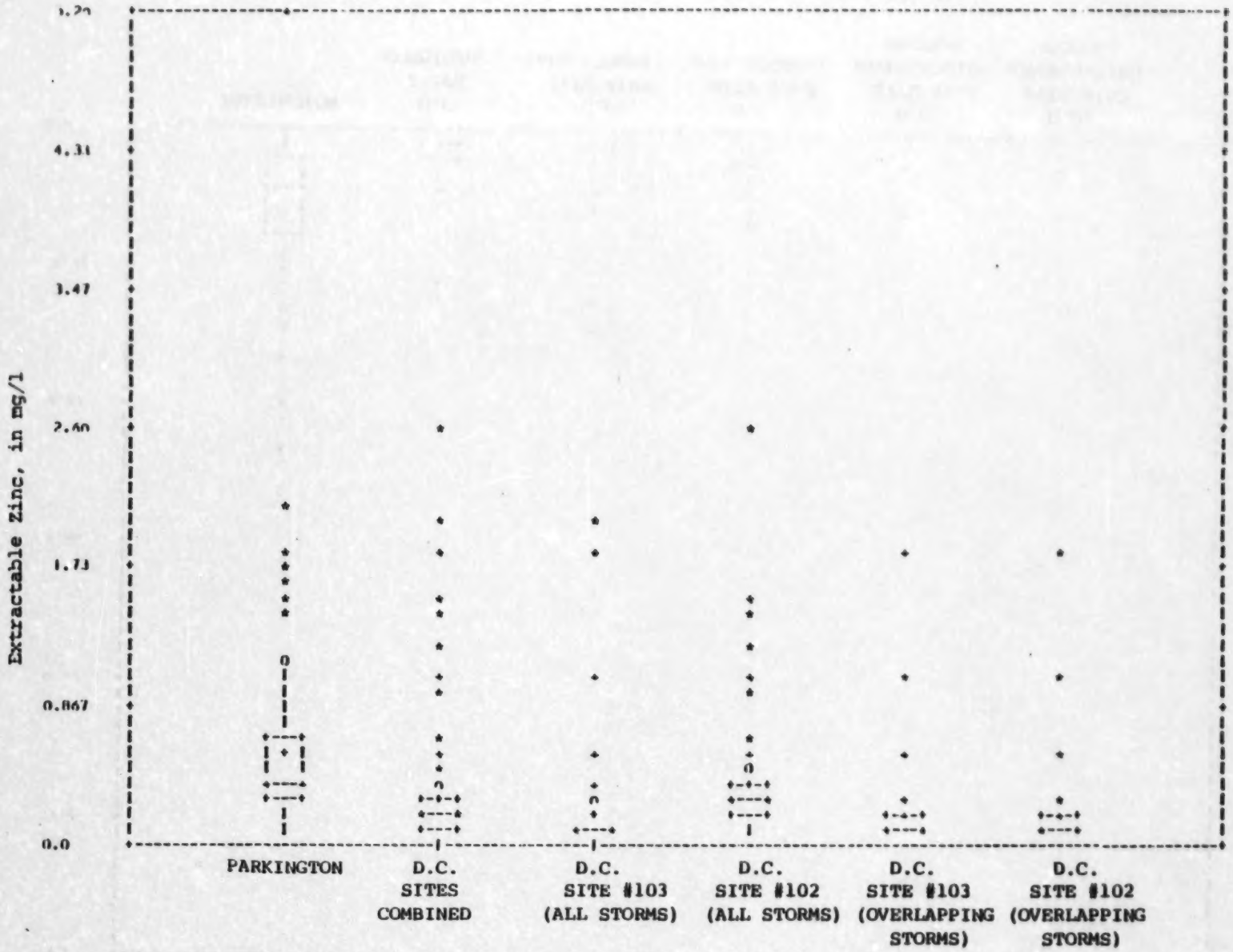
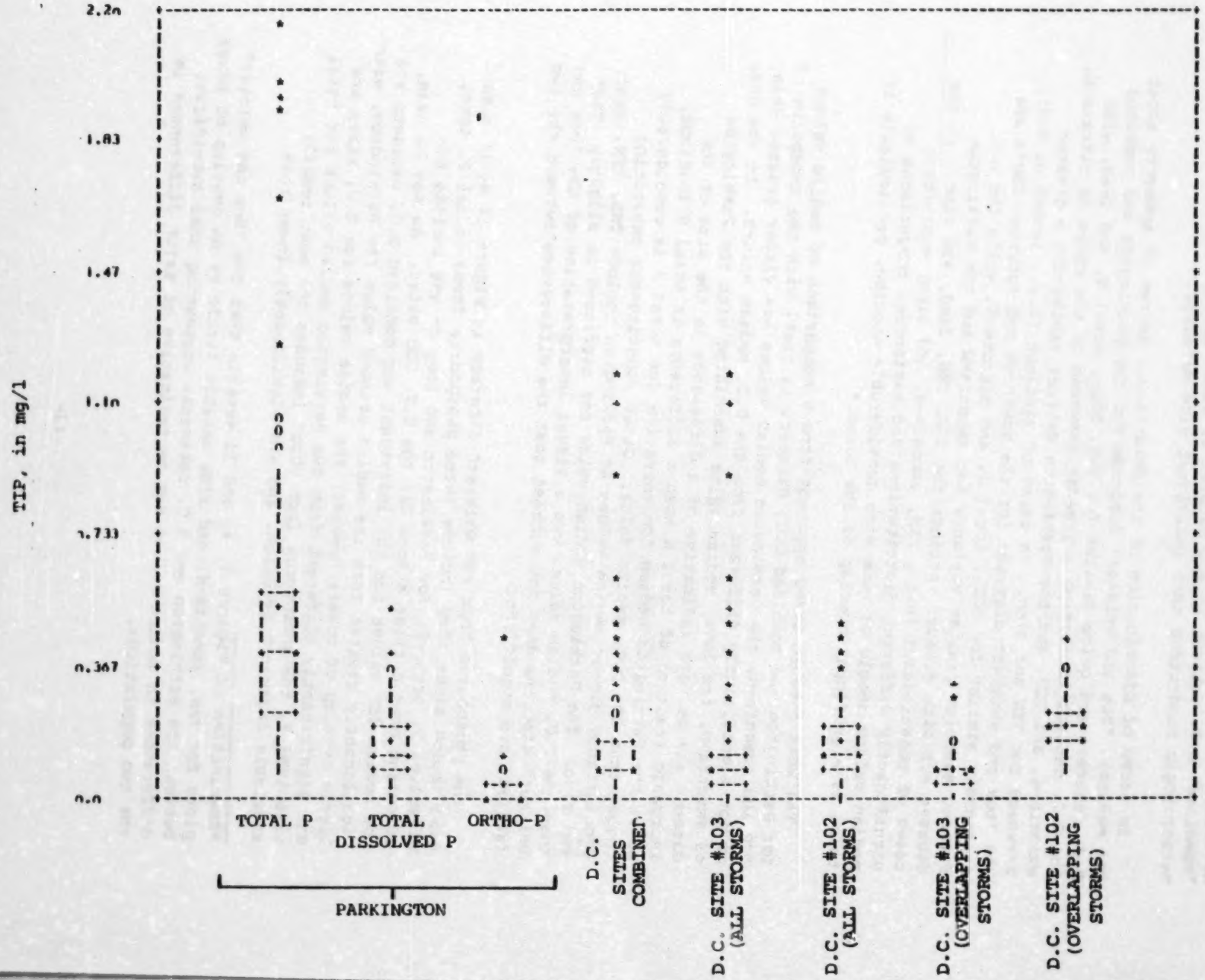


Figure 11. "Box and Whisker" Diagrams for Extractable Zinc.

Figure 12. "Box and Whisker" Diagrams for Phosphorus



advisable to base comparisons with the Parkington dataset on the "combined" D.C. dataset (i.e., dataset 2) which covers a wider range of meteorologic conditions than individual site datasets.

In terms of distribution of the data (i.e., degree of symmetry about the median), "box and whisker" diagrams for the Parkington and combined D.C. datasets are quite similar for TSS, BOD_5, total N, and lead, with the D.C. dataset exhibiting a greater skewness in the cases of nitrate-N, ammonia-N, and TIP, and the Parkington dataset exhibiting a greater skewness for TKN and zinc. In terms of variance (i.e., length of box), the "box and whisker" diagrams for the downtown and suburban CBD's are reasonably similar for BOD_5, total N, and nitrate-N, while the D.C. dataset exhibits greater variance for ammonia-N and the Parkington dataset exhibits greater variance for TSS, TKN, lead, and zinc. In the cases of constituents (e.g., TKN, ammonia-N, and zinc) exhibiting significantly different distributions and variances, comparisons of median values should be made with considerable caution, particularly if there is significant overlap of the boxes.*

The most notable trend apparent from a comparison of median values for Parkington and combined D.C. datasets is that, with the exception of TIP and ammonia-N, the Parkington median values are either greater than or not significantly different from the D.C. median values. In the case of ammonia-N, the lower median value associated with the Parkington dataset may be more indicative of a difference in the size of the inorganic fraction of total N than a difference in total N loadings, since the Parkington median concentration for total N is considerably higher than the D.C. median value. Other constituents exhibiting considerably higher median values at Parkington include TSS, TKN, lead, and zinc. The Parkington median value for nitrate-N is slightly lower than the D.C. median value, but a visual interpretation of the "box and whisker" diagrams does not suggest that the differences between the two datasets are significant.

The phosphorus "box and whisker" diagrams in Figure 12 merit some elaboration since they include three phosphorus forms (total P, total dissolved P, ortho-P) for Parkington and they do not include the aforementioned outlier storms for the D.C. CBD sites. As may be seen, the median TIP values for the individual and combined D.C. datasets are significantly greater than the median ortho-P value for Parkington, with little overlap of boxes; however, the median values for D.C. sites are not significantly different from the Parkington median values for total dissolved P, the phosphorus form which includes the most readily available organic P fraction, and are significantly lower than

*Examination of Figures 7, 9, and 11 reveals that the "box and whisker" plots for TKN, ammonia-N, and zinc exhibit little or no overlap of boxes between the Parkington and D.C. datasets, suggesting that significant differences in median values may be indicative of major differences in the two populations.

Parkington's median value for total P. In general, these comparisons are consistent with those presented earlier. It is not inconceivable that the significant difference between the median TIP value at the downtown CBD and the median ortho-P value at the suburban CBD is due to higher total P loadings from the D.C. sites. However, such a relationship is considered to be highly unlikely for the following reasons, most of which were cited in an earlier section of this report:

(a) The significantly higher median values for total N at the Parkington site and typical "N:P" ratios associated with runoff from highly impervious land uses tend to reduce the likelihood that total P loadings from the D.C. sites are significantly higher than Parkington levels.

(b) The anomalies in the "TIP:Ortho-P" comparisons in Table 6, and what appears to be a series of spurious TIP observations in Appendix A suggest that the errors incurred during the acid hydrolysis of runoff samples for TIP analysis could conceivably have resulted in significant overestimates of the TIP fraction of total P, particularly in light of the relatively high organic P fraction identified in Parkington runoff samples.

(c) In order for the D.C. CBD's higher median TIP values to be indicative of higher total P loadings at downtown CBD's, one must assume that the organic P fractions (96% of total P) are similar at downtown and suburban CBD's and therefore that the median organic P concentration for the D.C. dataset would be proportionately greater than the median organic P concentration for Parkington; however, if the D.C. CBD sites are characterized by significantly higher organic P loadings than Parkington, one would expect the median BOD concentration for the downtown CBD to be considerably higher than the suburban CBD's median value when in fact it is somewhat lower.

In light of all of the above, it is felt that if the higher median TIP value for the combined D.C. dataset suggests significant differences between phosphorus loading potential at downtown and suburban CBD's, it is more likely to be indicative of a higher inorganic P fraction of total P rather than a major difference in total P loadings. However, in the absence of total P data for the D.C. CBD sites, it is difficult to confirm or refute this hypothesis.

Summary and Recommendations

Monitoring data collected during two separate field studies has been compared to test the hypothesis that downtown CBD's exhibit higher nonpoint pollution loading rates than suburban CBD's. Due to the lack of flow data for the downtown CBD monitoring sites, comparisons of downtown and suburban loading potential had to be based upon instantaneous concentrations rather than storm event loads or mean concentrations

(i.e., total load divided by total runoff volume). The downtown CBD study's reliance upon TIP as the only indicator of phosphorus loading potential also complicated the analysis.

With the exception of TIP, a comparison of arithmetic mean concentrations in runoff from downtown and suburban CBD's does not support the hypothesis, although the relatively high standard deviations associated with most constituents suggest that the mean values may not be acceptable measures of central tendency. Likewise, with the exception of TIP and ammonia-N, applications of graphical nonparametric statistical techniques relying upon comparisons of median values rather than mean values did not support the hypothesis. Considerations such as typical relationships between total N and total P, between TIP and ortho-P (i.e., in the case of the October 1, 1979 storm at Site #103), and between organic P and BOD_5, and the possibilities for laboratory error during the manual steps in the TIP analysis, all suggest that higher TIP observations at downtown CBD's are probably more indicative of a greater inorganic fraction of total P than higher total P loadings; however, the absence of total P data prevents any conclusive statements about the significance of the relatively high TIP data monitored at downtown CBD's.

Given the above, the authors have arrived at the following conclusions and recommendations:

1) The comparison of Parkington and D.C. monitoring data does not indicate that downtown CBD's produce significantly higher nonpoint pollution loadings of TSS, BOD_5, total N, TKN, nitrate-N, lead, and zinc and therefore, the analysis does not indicate the need for any adjustments to Parkington nonpoint pollution loading factors for these constituents in order to apply them to downtown CBD's.

2) Since comparisons of "box and whisker" diagrams suggest that the D.C. CBD sites produce ammonia-N loadings which are significantly higher than Parkington loadings, it is recommended that the ammonia fraction of total N loadings for downtown CBD's be adjusted upward by the ratio of median values for D.C. and Parkington datasets (0.33:0.105). Therefore, the ammonia-N fraction for downtown CBD loading factors should be set at approximately 13% of total N rather than the 4% level which characterized Parkington runoff. In order to maintain the same TKN fraction of total N (approximately 78%) in downtown and suburban CBD runoff, in accordance with the results discussed herein, it is recommended that the organic N fraction for downtown CBD loading factors be set at 65% of total N rather than the 74% level which characterized Parkington. While these changes are relatively minor, they do reflect the trend toward slightly higher availability of nitrogen loadings that is evident from the D.C. CBD field study.

3) In the absence of downtown CBD loading data on the various phosphorus fractions, it is recommended that Parkington loading factors for total P be applied to downtown CBD's without further adjustment. Although it is conceivable that the significance of the inorganic P fraction of downtown CBD runoff was overestimated due to the opportunity for error in the acid hydrolysis stage of the TIP test, the comparisons of Parkington and D.C. phosphorus data do suggest that phosphorus loadings from downtown CBD's may be characterized by a higher ortho-P fraction. Thus, it is recommended that the ortho-P fraction (4% of total P) associated with suburban CBD loading factors be adjusted upward by the ratio (approximately 5.0) of the median TIP value at the D.C. sites to the median ortho-P value at Parkington to produce a conservative estimate of available phosphorus loadings for studies of downtown CBD's. Thus, the ortho-P fraction should be set at approximately 20% of the total P loading factor for downtown CBD's and 4% of the total P loading factor for suburban CBD's.'

4) Wetfall and nonpoint pollution loading data collected at highly impervious land uses during the NURP study may also clarify some of the differences between the Parkington and D.C. datasets. For example, wetfall data collected at downtown and suburban locations may help explain the greater significance of inorganic plant nutrient fractions observed during the D.C. CBD field study.

Acknowledgements

This study was directed by David J. Biggers, NVPDC Water Resources Engineer, who performed all the statistical analyses described herein. Assistance with the application of nonparametric statistical techniques was provided by Elizabeth M. Southerland, NVPDC Environmental Engineer. The mathematical modeling tasks were performed by John P. Hartigan, NVPDC Project Manager, who also prepared this report.

The assistance provided by O'Brien and Gere, Inc., particularly Greg Welter who arranged for the transfer of the D.C. CBD dataset to NVPDC and Dave Hill who provided supplementary information on the dataset and the CBD study's analytical program, is gratefully acknowledged

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A P P E N D I X A

TIME SERIES OF INSTANTANEOUS CONCENTRATIONS FOR SELECTED STORMS

Table A-1. Time Series of Instantaneous Concentrations (mg/l) for June 3, 1980 Storm at D.C. Site #102

YR	MO	DAY	HR	MIN	SEAS	SEAS1	BOD5	PB	NH3	TKN	TIP	TSS	ZN	FCOLI	NO23	TN
80	6	3	17	29	CSUNN	NONNI	9.20	0.016	0.7	1.1	0.70	15	0.33	60000	1.42	2.52
80	6	3	17	33	CSUNN	NONNI	11.20	0.025	1.0	3.3	1.20	55	0.36	13000	1.56	4.86
80	6	3	17	37	CSUNN	NONNI	9.10	0.024	0.4	1.3	0.33	30	0.20	23000	1.57	2.87
80	6	3	17	40	CSUNN	NONNI	11.20	0.021	1.5	2.6	0.60	60	0.41	700	1.56	4.16
80	6	3	17	44	CSUNN	NONNI	3.96	0.031	1.5	1.5	0.65	40	0.30	12000	1.63	3.13
80	6	3	17	48	CSUNN	NONNI	10.70	0.022	0.6	1.5	0.73	30	0.33	4700	1.64	3.14
80	6	3	17	52	CSUNN	NONNI	10.30	0.013	0.4	.	0.27	20	0.27	45000	1.79	.
80	6	3	17	55	CSUNN	NONNI	10.10	0.013	0.4	1.0	0.31	10	0.26	39300	1.69	3.49
80	6	3	17	59	CSUNN	NONNI	9.80	0.010	0.8	1.5	0.24	20	0.23	4900	1.49	3.19
80	6	3	18	3	CSUNN	NONNI	10.10	0.003	0.7	1.1	0.31	10	0.29	4300	1.44	2.74
80	6	3	18	7	CSUNN	NONNI	9.10	0.003	0.3	1.1	7.72	10	0.24	8000	1.71	2.81
80	6	3	18	10	CSUNN	NONNI	9.80	0.001	2.1	2.1	5.98	25	0.25	2900	1.97	4.07
80	6	3	18	14	CSUNN	NONNI	9.80	0.003	0.7	1.8	2.85	5	0.26	66000	1.91	3.71
80	6	3	18	18	CSUNN	NONNI	9.80	0.004	1.0	.	4.90	5	0.41	12600	2.73	.
80	6	3	18	22	CSUNN	NONNI	10.80	0.007	0.8	1.8	1.40	10	0.30	1500	2.50	4.30

Table A-2. Time Series of Instantaneous Concentrations (mg/l) for October 1, 1979 Storm at D.C. Site #103

YR	MO	DAY	HR	MIN	SEAS	SEASI	BOD5	P	NH3	TKN	TIP	TSS	ZN	FCOLI	NO23	TN
79	10	1	0	0	DFALL	NONWI	10	0.18	.	.	.	.	.	.	.	.
79	10	1	5	15	DFALL	NONWI	25	.	.	.	4.50	174	.	200	.	.
79	10	1	5	19	DFALL	NONWI	21	.	.	.	16.07	177	.	19600	.	.
79	10	1	5	23	DFALL	NONWI	14	.	.	.	5.13	588	.	1500	.	.
79	10	1	5	27	DFALL	NONWI	57	.	.	.	4.87	196	.	3300	.	.
79	10	1	5	30	DFALL	NONWI	6	.	.	.	3.17	50	.	2900	.	.
79	10	1	5	34	DFALL	NONWI	3	.	.	.	9.67	79	.	2000	.	.
79	10	1	5	38	DFALL	NONWI	2	.	.	.	1.52	44	.	3000	.	.
79	10	1	5	42	DFALL	NONWI	.	.	.	.	1.59	19	.	2200	.	.
79	10	1	5	45	DFALL	NONWI	2	.	.	.	2.40	17	.	2100	.	.
79	10	1	5	49	DFALL	NONWI	1	.	.	.	1.84	10	.	2500	.	.
79	10	1	5	53	DFALL	NONWI	5	.	.	.	0.50	4	.	4300	.	.
79	10	1	5	57	DFALL	NONWI	2	.	.	.	1.44	9	.	1900	.	.
79	10	1	6	0	DFALL	NONWI	3	.	.	.	2.70	15	.	800	.	.
79	10	1	6	4	DFALL	NONWI	8	.	.	.	1.84	8	.	1900	.	.
79	10	1	6	8	DFALL	NONWI	3	.	.	.	2.94	7	.	23000	.	.
79	10	1	6	12	DFALL	NONWI	3	.	.	.	1.21	7	.	14000	.	.
79	10	1	6	15	DFALL	NONWI	4	.	.	.	.	43	.	2100	.	.
79	10	1	6	19	DFALL	NONWI	3	.	.	.	.	16	.	400	.	.
79	10	1	6	23	DFALL	NONWI	.	.	.	.	2.71	7	.	1900	.	.
79	10	1	6	27	DFALL	NONWI	.	.	.	.	4.28	12	.	2400	.	.
79	10	1	6	30	DFALL	NONWI	40	.	.	.	2.46	33	.	2500	.	.
79	10	1	6	34	DFALL	NONWI	5	.	.	.	4.45	32	.	1300	.	.
79	10	1	6	38	DFALL	NONWI	4	.	.	.	5.40	102	.	5200	.	.
79	10	1	6	42	DFALL	NONWI	10	.	.	.	6.01	37	.	1000	.	.

Table A-3. Time Series of Instantaneous Concentrations (mg/l)
for June 3, 1980 Storm at D.C. Site #103

YR	MO	DAY	HR	MIN	SEAS	SEAS1	BOD5	PB	NH3	TKN	TIP	TSS	ZN	FCOLI	NO23
80	6	3	0	0	CSUMM	NONWI	.	0.072	.	.	0.350	.	0.224	.	.
80	6	3	17	0	CSUMM	NONWI	304.00	1.170	1.3	2.6	2.550	840	1.830	740000	0.32
80	6	3	17	4	CSUMM	NONWI	63.30	0.040	0.5	8.0	15.200	57.0	1.040	500000	0.48
80	6	3	17	8	CSUMM	NONWI	14.20	0.390	0.4	2.9	13.500	210	0.550	1330000	0.76
80	6	3	17	12	CSUMM	NONWI	12.70	0.123	0.9	4.1	18.800	80	0.250	282600	0.83
80	6	3	17	15	CSUMM	NONWI	11.70	0.092	0.5	5.1	0.300	80	0.220	49000	0.91
80	6	3	17	19	CSUMM	NONWI	11.50	0.058	0.5	1.8	11.400	75	0.170	210000	0.85
80	6	3	17	23	CSUMM	NONWI	8.55	0.010	0.6	2.2	4.800	60	0.150	33500	0.91
80	6	3	17	27	CSUMM	NONWI	8.40	0.025	0.6	2.1	1.880	50	0.150	73000	1.01
80	6	3	17	30	CSUMM	NONWI	8.50	0.024	1.1	1.9	3.800	45	0.150	124000	1.12
80	6	3	17	34	CSUMM	NONWI	8.30	0.014	1.0	1.5	3.600	40	0.150	77000	1.23
80	6	3	17	38	CSUMM	NONWI	8.20	0.013	0.7	2.3	3.200	40	0.170	60000	1.34
80	6	3	17	42	CSUMM	NONWI	9.20	0.015	0.7	2.7	0.300	55	0.150	46000	1.18
80	6	3	17	45	CSUMM	NONWI	8.60	0.010	0.6	1.8	0.690	35	0.150	40000	1.38
80	6	3	17	49	CSUMM	NONWI	7.30	0.013	0.6	3.0	0.690	45	0.150	424000	1.38
80	6	3	17	53	CSUMM	NONWI	7.30	0.012	1.2	1.3	2.550	40	0.140	42000	1.41
80	6	3	17	57	CSUMM	NONWI	7.70	0.009	0.7	2.6	4.780	5	0.130	22200	1.82
80	6	3	18	0	CSUMM	NONWI	8.30	0.007	0.7	2.6	0.490	15	0.130	190000	1.62
80	6	3	18	4	CSUMM	NONWI	7.70	0.009	0.6	1.3	1.450	10	0.110	130000	1.34
80	6	3	18	8	CSUMM	NONWI	7.80	0.007	0.7	1.7	.	5	0.120	143000	1.63
80	6	3	18	12	CSUMM	NONWI	9.70	0.008	0.7	1.8	0.250	15	0.140	10000	1.33
80	6	3	18	15	CSUMM	NONWI	7.40	0.005	0.7	2.6	0.150	5	0.130	420000	1.53
80	6	3	18	19	CSUMM	NONWI	7.40	0.007	0.7	6.9	0.175	.	0.130	14500	1.65
80	6	3	18	23	CSUMM	NONWI	7.10	0.005	1.1	1.1	0.180	20	0.130	2980	1.71
80	6	3	18	27	CSUMM	NONWI	7.08	0.009	0.7	4.0	0.310	15	0.160	200000	1.78